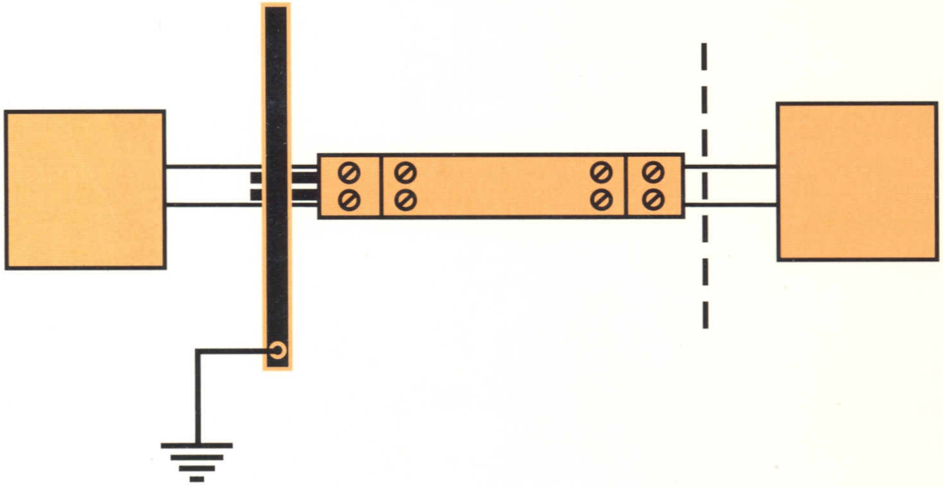
Weidmüller

Intrinsically Safe Instrumentation: a guide



Special Edition

Robin Garside has been actively involved with hazardous areas and electrical apparatus for many years and has always had a particular interest in intrinsic safety. He has designed two complete ranges of zener safety barriers as well as numerous items of intrinsically safe apparatus and is familiar with the standards and requirements both in Europe and North America.

He is a member of several BSI committees concerned with hazardous areas, including the committee on intrinsic safety which contributes to the CENELEC standard, but is always keen to emphasise the practical aspects of the subject as well as the requirements of the standards. He is well known for his straightforward approach to problem solving on site.

Since 'Intrinsically Safe Instrumentation: a guide' was first published in 1982 it has become a standard reference work for many engineers and technicians involved with this area of technology. His second book, 'Electrical Apparatus and Hazardous Areas', first published in 1991 and revised to its second edition in 1994, is a companion volume covering other protection techniques.

Robin Garside is Director and Principal Consultant of Hexagon Technology Limited, an engineering consultancy specialising in hazardous areas.

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Intrinsically Safe Instrumentation: a guide

Special Edition

Robin Garside

Special Edition 1996

Whilst every effort has been taken to ensure the accuracy of the information in this book, neither the author or publisher may be held responsible for any inaccuracies or for any changes to established procedure or National, European or International Standards, or European Directives etc. which may occur. It is the reader's responsibility to check the latest requirements which may apply to any application or installation.

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Note Regarding Special Edition

This copy of 'Intrinsically Safe Instrumentation: a guide', is, apart from the cover, this note, the removal of the ISBN and the removal of the Acknowledgements page, identical in all respects to the version published as ISBN 0 9516848 1 7 at its Third Edition, 1995. The general version is available from normal book sales outlets or direct from the publishers.

This special edition has been produced in association with Weidmuller Interface Limited, Intrinsic Safety and Electronics Division and is only available from them and their Agents as technical support for their intrinsically safe product range. It is not for general sale.

Weidmuller's involvement with intrinsic safety goes back many years and was strengthened in 1990 with the acquisition of Safety Technology Limited, (STL) formerly part of the Gresham Lion Group which produced the early barriers in the 1960's and more recently was at the forefront of IS multiplexer development.

Weidmuller Interface Limited, Intrinsic Safety and Electronics Division is based in Kent, England and is the Weidmuller centre for intrinsic safety product development and manufacturing. It provides world-wide sales, marketing, technical and training support services for intrinsic safety products throughout Weidmuller Group Companies, Agents and Distributors.

Preface

It is now 13 years since the first edition of 'Intrinsically Safe Instrumentation - a guide'. Since that time the technology of intrinsic safety has developed significantly, and, although already revised to a second edition (in 1988) I felt the time had come to take a completely fresh look at the subject, giving greater emphasis to European and IEC standards as opposed to National standards and in effect to re-start from scratch.

There are a number of points which the reader should note at this stage. Firstly, the companion book to this volume 'Electrical Apparatus and Hazardous Areas' covers the broader aspects of hazardous areas, and thus, with the exception of a brief chapter summarising other methods of protection, this book does not concern itself with anything not directly related to intrinsic safety.

Secondly, the recent publication of the second edition of the European CENELEC Standard on intrinsic safety - EN 50 020 - will make some significant differences to the ways in which intrinsically safe apparatus is designed and installed. Some of those changes are, in my view, for the better, some for worse. Since there is never a complete cut off with new Standards, the first edition of EN 50 020 and apparatus certified to the first edition, will continue to be available for some time. Although based on the second edition, both editions are covered in this book.

Thirdly, over the coming years the influence of various EC Directives will start to alter the approach to hazardous areas significantly and, although the full ramifications of this are outside this book, there are implications for intrinsic safety which are worth investigating.

'Intrinsically safe instrumentation: a guide', has been written so that each chapter will, to a great extent, stand alone. Cross-referencing

to other parts of the book, as well as a comprehensive index, will make locating information as easy as possible, whilst enabling the reader to obtain a succinct understanding of a particular topic without the need to read unnecessary text. The reader should remember, however, that few matters can be regarded in total isolation and the chapters have been arranged so that progression through the book covers the subject in a logical and comprehensive sequence.

I have also given some thought to the inclusion of intrinsic safety in various training courses. This book will adequately cover all the aspects necessary for technicians, installers and maintenance personnel who need a reference book to accompany the training which will be required before working on intrinsically safe apparatus on site.

If any reader notices any omissions or has suggestions for additional topics for future editions, please write and tell me.

Robin Garside
January 1995

Contents

Note on the use of Footnotes and References

Throughout the book, technical references and references to standards etc. are flagged in the text by a reference number thus: [1]. The relevant note or reference will be found at the end of the chapter.

Non-technical notes, expansion of a point in the text, comments which are of marginal influence on the subject, or the author's personal view or comment are denoted by an asterisk [*] and the relevant text appears as a footnote on that page.

Note on Drawing Convention used in this Book

Throughout this book, block diagrams showing circuits which are partially in the hazardous area and partially in the non-hazardous area are arranged so that the non-hazardous area is on the left side of the diagram, and the hazardous area (or hazardous area terminals of associated apparatus) to the right. Although this convention is very common, some publications, manufacturers' catalogues etc. use the opposite layout. Readers should always be careful when viewing such diagrams to ensure that the hazardous and non-hazardous sides are clearly understood.

Note on Standards

Throughout this book the advice and requirements of the CENELEC Standards have been followed. Since the CENELEC and IEC Standards now include equivalent text, this will mean that variations throughout the world will gradually become less pronounced. Where reference to national standards such as the UK Code of practice gives greater clarity, national standards have been used, and reference to this fact has been made in the text. Readers should also note that there are significant differences between the first and second editions of the CENELEC Standard for intrinsically safe apparatus (EN 50 020). This book is based on the second edition but, where appropriate, the differences are explained and techniques which may be employed for apparatus and systems designed to the first edition are also explained.

CHAPTER 1

Introduction to Electrical Equipment in Hazardous Areas

This chapter includes information on
Basic hazardous area terminology Explanation of gas groups, zones, temperature classes Sources of ignition

Introduction to Electrical Equipment in Hazardous Areas

Industrial operations often involve using, processing or storing hazardous (flammable) materials. Clearly the plant associated with these operations needs to be arranged and controlled in such a way that these materials do not catch fire or explode, causing damage to people and plant.

There are a great number of potential ignition sources, such as unauthorised smoking and use of naked flames, hot surfaces from the process itself, frictional sparking from rusty metals and static electricity - including problems from clothing. Most of these sources of ignition can, at least to some extent, be controlled and minimised, and this comes under the heading of good plant management and control. There is however an additional problem. The electrical apparatus necessary to operate the plant, for pumps, fans, lights, instrumentation and other equipment, is itself a potential source of ignition. Thus the very apparatus which should be serving to provide better control over the plant and process may be making the site more, rather than less, dangerous.

It is worth bearing in mind that electricity can give rise to ignition of hazardous material in two ways; by electrical arcs and sparks, and by hot surfaces resulting from the heat dissipation of apparatus. Both of these aspects will be considered in this book, and it should be understood at the outset that from the viewpoint of the hazard, there is no connection between these two ignition sources. Hazards which will ignite with very little spark energy may have quite high ignition temperatures.

From the preceding paragraphs it should be clear that all electrical equipment which is to be located in (or in some cases even outside) the hazardous area needs to be designed and installed in such a way that the risk of it causing ignition is known and controlled to an acceptable (low) level. This control is achieved by using one or

more of several available and established methods of protection. Not all of these methods of protection are suitable for all applications. For example, the technique of increased safety is not suitable for switchgear; purge-pressurized protection is not suitable for smaller apparatus. This book is especially concerned with the protection concept of intrinsic safety, which is a technique whereby the electrical power is limited to very low levels so that electrical arcs and sparks will not be ignition capable. Thus intrinsic safety achieves its protection against ignition by removing the source of ignition.

Although the other methods of protection are adequately covered elsewhere, [*] for the sake of completeness, and because it is becoming increasingly common for one item of electrical equipment to employ more than one method of protection, all the different methods of protection are summarised in Chapter 2.

Flammable Atmospheres - Terminology and Classification

The Flammable Material

The mechanism by which ignition takes place is usually explained by reference to the ignition triangle. This shows that for combustion to occur three properties must be present; the flammable material, a supporter of combustion and the source of ignition.

Many substances can be ignited - wood, coal, plastics and so on - but it is really the gas or vapour from substances which burns, and most materials need to be heated to quite high temperatures before sufficient gas or vapour is released. Thus as far as inadvertent ignition by electrical apparatus is concerned, the problem is confined to those materials which readily give off sufficient gas or

* See 'Electrical Apparatus and Hazardous Areas' ISBN 0 9516848 0 9 by the same author.

vapour at the temperatures likely to be encountered in and around the electrical apparatus. Mostly, these materials are either already in a gaseous or vapour form, or are liquids which have a relatively low flash point,[*] such as solvents, petroleum, and alcohol. Such substances are in common use throughout industry and, unless the quantity is very small, the locations involved will be regarded as **hazardous areas**. Additionally, dusts can give rise to hazardous atmospheres, and this causes special problems because, unlike gases and vapours, dusts can accrue over a period of time, building up layers of dust on equipment. Dust flammability hazards are often encountered in breweries (grain dust), food processing (flour etc.) and of course mining industries (coal dust). The use of intrinsic safety in dust hazard environments will be looked at separately in Chapter 16.

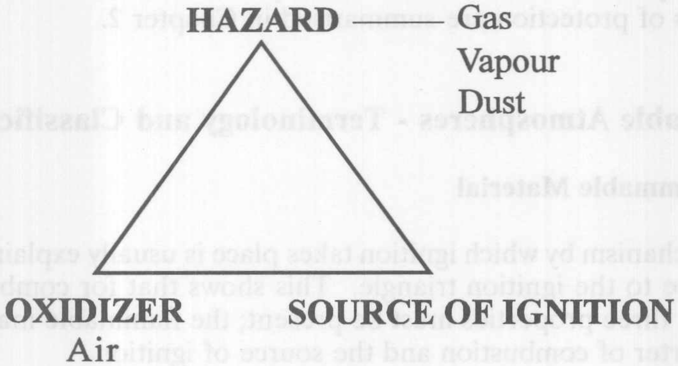

Figure 1.1 *The Ignition Triangle*

* **Flash point** is defined as the temperature (of a substance) at which sufficient vapour (or gas) is given off that ignition of the vapour can take place and then be self-sustaining if a source of ignition is available to start the process. Flash point must not be confused with ignition temperature - also called ***auto ignition temperature*** or ***spontaneous ignition temperature*** - which is the temperature at which the material can self-ignite without a separate source of ignition to start the process.

The Oxidizer

The oxidizer is the supporter of combustion, and is normally air. The air we breath contains about 21% oxygen by volume, and the various regulations, Standards and Codes of practice usually explicitly confine their requirements or advice to hazardous atmospheres with atmospheric oxygen content at the normal atmospheric pressures. This is perfectly adequate for most purposes, but there are occasions where oxygen enrichment can occur together with (or resulting in) a flammable material. In such circumstances, additional precautions to those determined by the Standards and Codes will be required, and specialist advice may well be necessary. Fortunately, such situations are fairly rare, and any oxygen enrichment which does occur - for example a leaking valve from an oxygen cylinder - is usually so localised to a defined source that problems can be overcome by ensuring that there is no source of ignition in that immediate area. [1]

The Source of Ignition

In this book, the consideration is the possible source of ignition from electrical equipment; either as a provider of electrical arcs and sparks, or as a provider of hot surfaces (or both).

Defining Hazardous Areas

As already explained, some materials are more easily ignited than others. Even within the range of flammable liquids [*] such as solvents, petroleum etc. there are large variations in ignition properties. The ease with which hazardous materials can be ignited determines into which gas group they are placed. For most of the commonly encountered flammable materials, the gas group is

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* As already explained, it is really the vapour from the liquid which is flammable; the liquid itself will not burn!

already established, and tables exist which give this information.[2] The International Electrotechnical Commission (IEC) defines two main gas groups; group I for the mining industry and group II for surface industry.[*] Group II is subdivided into three sub-groups, A, B, and C, thus giving IIA, IIB and IIC. The most easily ignitable hazards are categorised as IIC. This sub-group includes Hydrogen, Acetylene and Carbon Disulphide,[**] with hydrogen being the typical gas.[3] Groups IIA and IIB contain most of the common solvents, petroleum, and so on. The typical gas for group IIB is ethylene and for group IIA propane. Group I is typically methane (firedamp). So the first step is to find out what the hazard is, and thus establish which gas group is applicable. This is important because not all apparatus is suitable (safe) for all gas groups.

<table>
<tr><th>Typical Gas</th><th>IEC Gas Group</th><th>North America Gas Group</th></tr>
<tr><td>Methane</td><td>I</td><td rowspan="2">Class I, Group D</td></tr>
<tr><td>Propane</td><td>IIA</td></tr>
<tr><td>Ethylene</td><td>IIB</td><td>Class I, Group C</td></tr>
<tr><td>Hydrogen</td><td rowspan="2">IIC</td><td>Class I, Group B</td></tr>
<tr><td>Acetylene</td><td>Class I, Group A</td></tr>
</table>

Table 1.1 *Comparison of IEC and American Gas Groups*

North America, although taking an active part in the IEC, tends to still use its own classification terminology and procedure. Instead of gas groups, America has three classes; Class I for gases and vapours, Class

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* Surface industry really includes everything other than mining, so even an underground chamber or a sump which is below ground level will still fall within the classification of group II.

** Actually, apart from these gases, there are no common hazards in group IIC.

II for dusts and Class III for fibres. Within each class there are various sub-groups as indicated above. It should be noted that the sub-group letters for gases and vapours are opposite to the sub-group letters used by the IEC system.

The next part of the hazardous area [*] definition concerns probability. Obviously whatever the actual hazard may be (that is, whatever the gas group), the likelihood of the hazard being present *at concentrations between the lower explosive limit (LEL)* [4] *and upper explosive limit (UEL)* will vary from place to place. For example, the vapour space above a flammable liquid in a fixed roof tank which has a breather, is likely to be at flammable concentrations for much, if not all, of the time. On the other hand, the space around a gasketed flanged joint on a pipe containing a flammable liquid is most unlikely to be at flammable concentrations except under fault conditions when the gasket blows out or crumbles with age.

The likelihood of the hazard being present is defined by the zone number. There are three zones for gas and vapour hazards and two zones for dust hazards.[5]

Zone Number	Source of Release	Likely Existence of Hazard
0	Continuous	Continuous / long periods
1	Primary	Possibly present under normal process conditions
2	Secondary	Present under fault conditions / for short periods

Table 1.2 *Zone Numbers and Likely Presence of Hazard*

* Although it is traditional to refer to hazardous areas, they are really volumes, since the hazard will spread in three dimensions.

With gas and vapour hazards, the smaller the zone number, the greater is the likelihood of the hazard being present at flammable concentrations. The area (volume) over which the risk is deemed to exist is thus referred to as a zone 0, or zone 1 or zone 2 area. The procedure of area classification is outside the scope of this book, and is covered in the companion volume: 'Electrical Apparatus and Hazardous Areas'. The two zones for dust hazards are zones Y and Z. Zone Z is the most severe risk, with zone Y being similar to zone 2.

The safety precautions which are taken to prevent an ignition source are dependent on the likelihood of the hazard being present - thus on the zone number.

Zone	Permissible Method(s) of protection	Code Letter(s) Ex / EEx ..
0	Intrinsic Safety category 'ia' (Special Protection 's' if certified specifically for zone 0 and used in country of certification.)	ia (s)
1	Any method of protection suitable for zone 0, plus .. Intrinsic safety category 'ib' Flameproof Increased safety Purge/pressurize Encapsulation Oil immersion Sand/Powder filling	 ib d e p m o q
2	Any method of protection suitable for zones 0 and 1, plus .. n-type protection	 n

Table 1.3 *Suitability of Methods of Protection According to Zone of Installation and Use*

As can be seen from Table 1.3, not all the methods of protection provide the same level of safety from ignition - that is to say, some methods of protection give a greater protection than others. Thus not all methods of protection are suitable for all zones. For example, **n-type protection** is only suitable for zone 2 use, whereas **flameproof protection** is suitable for use in zones 1 and 2. **Intrinsic safety** gives the safest of all methods of protection, and is suitable for zones 0, 1 and 2. [6]

In North America the term ***division*** *is often used instead of zone.* [*] *There are two divisions, 1 and 2. Division 2 is similar to zone 2 and division 1 broadly encompasses zone 0 and 1. The comparison between zones and divisions is shown in Table 1.4.*

Zone	Division
0	1
1	
2	2

Table 1.4 *Comparison of Zones and American Divisions*

Temperature Class

The third part of the hazardous area definition concerns the ignition temperature (auto ignition temperature) of the flammable material. It is important to ensure that electrical (and other) apparatus does not provide a source of ignition by being so hot that it is able to heat gases or vapours to a temperature at which the gas or vapour will self-ignite. The temperature at which self-ignition occurs is

* The term division used to be used in the UK and other countries. Although zones and divisions have similar meanings, they are not defined in the same way and should not be confused. Do not talk about divisions unless you mean to refer to American terminology.

called the ignition temperature. Rather than referring to the actual temperature of any hazard, the IEC defines six temperature classes; T1 to T6, corresponding to temperatures as indicated in the table. Electrical apparatus which is intended for use in hazardous areas is marked with the T-Class number appropriate to the maximum temperature it may exhibit.[*]

T-Class	Maximum Temperature °C
1	450
2	300
3	200
4	135
5	100
6	85

Table 1.5 *Temperature Classes*

* This is not necessarily the *external* temperature. For some methods of protection such as flameproof protection and purge-pressurize protection it is indeed only the external temperature which is of interest as far as T-Class is concerned, but for other methods of protection, including intrinsic safety, both internal and external temperature are important.

In America the temperature classes are sometimes sub-divided to give smaller classes as shown in Table 1.6.

T-Class	**Maximum Temperature °C**
T1	450
T2	300
T2A	280
T2B	260
T2C	230
T2D	215
T3	200
T3A	180
T3B	165
T3C	160
T4	135
T4A	120
T5	100
T6	85

Table 1.6 *Temperature Sub-Classes used in North America*

SUMMARY

- For ignition to occur, a hazard, an oxidizer and a source of ignition must be present.

- The International Electrotechnical Commission provides definitions for hazardous areas. These include:

- The gas group - I (for mining) and IIA, IIB, IIC for surface industry. The gas group defines the ignitability of the hazard. Group IIC is for the most easily ignited hazards, typically hydrogen.

- The zone - 0, 1, 2 (or Y, Z or 21, 22, 23 for dust hazards) defines the likelihood of the hazard actually being present in flammable concentrations.

- The temperature class - T1, T2, T3, T4, T5, T6. The temperature classification on apparatus tells the user how hot it may get. This enables safety from ignition by hot surfaces to be ensured.

NOTES AND REFERENCES

1. There are several sources of additional information on oxygen enriched atmospheres, but one of the most helpful is published by the National Fire Protection Association (NFPA) in USA as standard number 53M, entitled Fire Hazards in Oxygen Enriched Atmospheres.

2. Tables of properties of hazardous (flammable) materials are published in some of the Standards and in the UK Code of Practice - BS 5345: Part 1.

3. The typical gases; Hydrogen for group IIC, Ethylene for group IIB and Propane for group IIA are used, at the most easily ignitable concentration when mixed with air, as the test gas when assessing the suitability of equipment for certification.

4. The Lower Explosive Limit (LEL) is the lowest concentration of a flammable gas or vapour mixed with air that is capable of sustaining the propagation of flame.

   The Upper Explosive Limit (UEL) is the greatest concentration of the gas or vapour mixed with air that is capable of sustaining the propagation of flame.

   Explosive limits are usually expressed as a % volume of the gas in air, but may be expressed as mass per unit volume (eg: mg/L).

5. Dust hazards will soon be classified by three zones: zone 20, 21 and 22 - equating in general concept to the zone 0, 1 and 2 of gas/vapour hazards. This change results from European legislation and is considered in more detail later in this book.

6. There are really two separate methods of protection under the general heading of intrinsic safety - category 'a' and category 'b'. The code letter for intrinsic safety is 'i', and thus there are two codes; 'ia' and 'ib'. Only intrinsic safety 'ia' is suitable for

all zones (including zone 0). Intrinsic safety 'ib' is suitable for zones 1 and 2 but not zone 0. The differences between 'ia' and 'ib' are explained in detail later on.

For a full explanation of the distinction between 'ia' and 'ib' see Chapter 5.

CHAPTER 2

Summary of Different Methods of Protection

This chapter includes information on	
N-Type protection	Ex n
Flameproof protection	Ex d
Purge / pressurize protection	Ex p
Increased safety	Ex e
Oil immersion	Ex o
Sand / powder filling	Ex q
Special protection	Ex s
Encapsulation	Ex m
Intrinsic safety	Ex ia/ib

Summary of Different Methods of Protection

Although this book is about the protection technique of intrinsic safety, it is quite common for more than one method of protection to be used on any one item of apparatus. Furthermore, there are circumstances when the other methods of protection need to be used to achieve intrinsic safety.

This chapter briefly reviews the different methods of protection, explaining how each technique is achieved, what it is commonly used for and, where applicable, how it may be used with, or influence, intrinsic safety.

For those readers already sufficiently familiar with other protection methods, this chapter may be skipped completely. For the reader wanting more detailed information on these methods of protection, they are covered in depth in the companion volume to this book; 'Electrical Apparatus and Hazardous Areas'.

n-Type Protection		
Code	Ex n, Ex N [1]	
Standards	IEC	79-15
	Europe	EN 50 021 [2]
	UK	BS 4683: Part 3 BS 6941 BS 5000 Part 16 (Motors) BS EN 50 021 [3]
Code of Practice	BS 5345: Part 7 BS EN 50 154 [4]	
Zone of Use	2	
Live Maintenance	Not without special precautions	
Typical Uses	Rotating machines, lighting, junction boxes, (some instrumentation)	

The method of protection 'n' relies on good construction; environmental protection to at least IP54 (see Appendix 5), mechanical strength tested by 3.5 Newton metre impact test, and is electrical apparatus which is **non-sparking in normal operation.** [*]

Not the subject of a CENELEC Standard at present (thus only Ex n or Ex N) although there is a CENELEC Standard in preparation.

The original concept of Ex n was to permit the use of normal industrial grade non-sparking apparatus in a zone 2 area. Because some countries' standards do not require zone 2 apparatus to be certified,[**] some Ex n apparatus will have been 'self-certified' by the manufacturer.

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* This means that n-type protection cannot be used for the protection of apparatus such as switches (unless the switch contacts themselves are protected by another method of protection).

** The UK Code of practice, BS 5345: Part 1 allows for uncertified apparatus to be used in zone 2.

Flameproof Protection		
Code	Ex d, EEx d	
Standards	IEC	79-1
	Europe	EN 50 018
	UK	BS 229 [5] BS 4683: Part 2 BS 5000: Part 17 (motors) BS 5501: Part 5 BS EN 50 018 [6]
Code of Practice	BS 5345: Part 3 EN 50 154 [4]	
Zones of Use	1 & 2	
Live Maintenance	No	
Typical Uses	Rotating machines, lighting, switchgear, junction boxes, instrumentation, start/stop buttons etc.	

Flameproof protection relies on mechanical construction to ensure that any ignition of the hazard inside the enclosure will not transmit to, and ignite, the atmosphere outside the enclosure. It is similar in principle to the technique of explosionproof which is widely used in North America.

Equipment protected by method of protection 'd' usually requires certification for each specific application, although there are a number of general approvals which allow the user to put a variety of apparatus inside a certified enclosure without invalidating the certificate, e.g. combinations of terminals, zener barriers, relays.

May be suitable for all gas groups, although for group IIC special requirements are needed usually resulting in boxes with screw tops, etc.

Maximum gap between lid and body of box specified. Note: flameproof boxes are not necessarily waterproof. The flange (gap) may be sealed with non-setting grease to increase weather protection.

Must use correct (component certified) cable gland - either compound filled gland (stopper gland) or compression gland depending on volume and contents of enclosure and classification of point of installation.

Flameproof protection 'd' Typical uses in conjunction with intrinsic safety
Used for the location of 'associated apparatus' [*] such as zener barriers and galvanic isolators when the associated apparatus cannot be located (mounted) in a non-hazardous area. The flameproof enclosure, together with all its cable entries etc. must fully comply with the requirements of flameproof protection; it is only the output from the associated apparatus - which will be coded [EEx ia] IIC etc. - which is intrinsically safe.

* 'Associated apparatus' is the term given to electrical apparatus such as zener barriers and other interface units. Associated apparatus is apparatus on which intrinsic safety depends, but at least part of the apparatus is not itself intrinsically safe. Associated apparatus is normally located in the non-hazardous (safe) area.

Purge/Pressurize Protection		
Code	EEx p	
Standards	IEC	79-2
	Europe	EN 50 016
	UK	BS 5501: Part 3 BS EN 50 016
Code of Practice	BS 5345: Part 5 EN 50 154 [4]	
Zones of Use	1 & 2	
Live Maintenance	No	
Typical Uses	Control panels, VDU's, analysers	

Pressurization achieves its safety by ensuring that there is no hazardous atmosphere within the pressurized enclosure.

In order to attain the required degree of safety it is necessary to first purge the enclosure by opening a vent and passing clean air or inert gas through the enclosure, then shutting off the vent and over-pressurizing with clean air or inert gas, such that the pressure inside the enclosure is above the ambient pressure outside. The enclosure will have some monitoring electronics attached to ensure that these operations have been carried out before the apparatus inside the enclosure is powered up, and to shut off the power if the pressure fails. This monitoring apparatus usually encompasses other methods of protection: for example, intrinsically safe pressure sensors operating via zener barriers located in a flameproof box bolted onto the side of the purged container.

Pressurization 'p' Typical uses in conjunction with intrinsic safety
Intrinsic safety is often used as part of the control mechanism for the pressurized apparatus itself. For example, intrinsically safe circuits operating pressure switches may be used to control the pressurized enclosure.

Increased Safety		
Code	Ex e, EEx e	
Standards	IEC	79-7
	Europe	EN 50 019
	UK	BS 4683: Part 4 BS 5000: Part 15 (motors) BS EN 50 019
Code of Practice	BS 5345: Part 6 EN 50 154 [4]	
Zones of Use	1 & 2	
Live Maintenance	No	
Typical Uses	Rotating machines, lighting, junction boxes, terminals.	

The technique of increased safety relies on constructional safeguards to ensure that the apparatus does not contain normally arcing or sparking devices or hot surfaces that might cause ignition, under both normal operation and under specified fault conditions. Measures are applied to reduce the possibility of failure, and hence arcing or sparking of the normally non-sparking parts.

The technique is not applicable where rated voltages exceed 11 kV.

Cable glands to increased safety apparatus should either be of component certified type or, at the user's discretion and responsibility, may be other industrial cable gland which affords IP54 protection, will clamp the cable sufficiently to withstand the required pull test, and is mechanically strong.

Increased Safety 'e' Typical uses in conjunction with intrinsic safety
Some zener barriers are certified as increased safety components. This means that they can be installed within suitable component certified increased safety enclosures and thus be located within the hazardous area. The enclosure, cable glands and cable must be suitable for increased safety - it is only the output from the barrier which is intrinsically safe. Increased safety also has applications for some earth connections on intrinsically safe apparatus and circuits. See Chapter 14.

Oil Immersion		
Code	Ex o, EEx o	
Standards	IEC	79-6
	Europe	EN 50 015
	UK	BS 5501: Part 2 BS EN 50 015
Code of Practice	BS 5345 EN 50 154 [4]	
Zones of Use	1 & 2 [7]	
Live Maintenance	No	
Typical Uses	Low power transformers, distributed control systems.	

The technique achieves prevention of ignition of a surrounding hazardous atmosphere by immersing the electrical apparatus under oil. The second edition of the CENELEC Standard permits the use of mineral insulating oil or fluids such as silicone fluids. The apparatus within the oil must be non-sparking in normal operation, so the technique is not suitable for protecting switchgear.

Oil Immersion 'o' Typical uses in conjunction with intrinsic safety
Where oil immersion is used for apparatus such as distributed control systems, the signal inputs and outputs to the apparatus are often intrinsically safe. Thus oil immersed apparatus may contain intrinsically safe 'associated apparatus'.

Sand/Powder Filling		
Code	Ex q, EEx q	
Standards	IEC	79-5
	Europe	EN 50 017
	UK	BS 5501: Part 4 BS EN 50 017
Code of Practice	BS 5345 EN 50 154 [4]	
Zones of Use	1 & 2 [8]	
Live Maintenance	No	
Typical Uses	Power supplies for weighing apparatus with intrinsically safe outputs. Parts of telephones.	

The technique of sand or powder filling achieves its protection against ignition by submerging the electrical apparatus within very small glass beads. [*]

Sand/Powder Filling 'q' Typical uses in conjunction with intrinsic safety
Where sand/powder filling is used for power supplies, the outputs from the supplies are often intrinsically safe. Thus sand filled apparatus may contain intrinsically safe 'associated apparatus'.

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* The beads are about the size of grains of granulated sugar. Indeed, the filling medium looks very like granulated sugar!

Special Protection		
Code	Ex s	
Standards	IEC	None
	European	None
	UK	SFA 3009 [9]
Code of Practice	BS 5345: Part 8	
Zones of Use	1 & 2. (Also zone 0 if specifically stated on certificate.)	
Live Maintenance	No	
Typical Uses	Applications which can be demonstrated to be safe, but which are not covered by other methods of protection.	

The special protection concept exists to allow apparatus which does not meet the full requirements of other methods of protection, to be certified by a national test body such as BASEEFA to their own requirements. It has been used, in the past, for such items as the cintered discs on gas detectors, or for the encapsulated part of piezoelectric circuits which, apart from the possible output from the piezoelectric, would otherwise be intrinsically safe.

Encapsulation		
Code	EEx m	
Standards	IEC	79-18
	Europe	EN 50 028
	UK	BS 5501: Part 8
Code of Practice	BS 5345 EN 50 154 [4]	
Zones of Use	1 & 2	
Live Maintenance	No	
Typical Uses	Parts of circuits and small assemblies.	

NOTE:

Encapsulation, or 'potting' techniques are often used in the manufacture of zener barriers and other 'associated apparatus'. Such use is not, however, within the scope of protection concept 'm'.

Intrinsic Safety			
Code		Ex ib	Ex ia
Standards	IEC	79-11	
	Europe	EN 50 020 (apparatus) EN 50 039 (systems)	
	UK	BS 1259 SFA 3012 SFA 3004 (zener barriers) BS 5501: Part 7 (apparatus) BS 5501: Part 9 (systems) BS EN 50 020 (apparatus)	
Code of Practice		BS 5345: Part 4 EN 50 154 [4]	
Zones of Use		1 & 2	0, 1 & 2
Live Maintenance		Yes	
Typical Uses		Instrumentation and control	

NOTES AND REFERENCES

1. Although BS 4683: Part 3 and BS 6941 both refer to method of protection Ex N, BASEEFA have, in the past, used the code Ex n on some certificates. As far as this book is concerned, the distinction between the different standards is not of great significance.

2. CENELEC Standard EN 50 021 is not yet complete but should be published during 1995. Once published, it will be possible to certify EEx n as opposed to Ex n.

3. BS EN 50 021 will be the BSI number for the English language publication of EN 50 021. BSI will publish the standard once it has been agreed and published by CENELEC.

4. CENELEC Standard EN 50 154 (and thus BS EN 50 154) concerning 'electrical installations in potentially explosive gas atmospheres (other than mines)' is due for publication in 1995.

5. BS 229 was written primarily for the mining industry. Although there is still some apparatus available which is certified to this standard, it has generally been superseded by other standards. The standard itself is no longer available.

6. This is the second edition of EN 50 018, and will eventually replace BS 5501: Part 5.

7. May be restricted to zone 2 use in some European countries. This zone 2 restriction applies in the UK under the UK Code of practice BS 5345: Part 1, but the IEC standard and forthcoming European standard (EN 50 154) allow its use in zones 1 and 2. Most countries will alter their national requirements to follow the agreed IEC and European position.

8. Sand/powder filling is restricted to zone 2 use in some countries. This used to be the case in the UK, but EEx q is now generally accepted for zones 1 and 2 in the UK.

9. Published by BASEEFA. There is no UK standard published by BSI.

CHAPTER 3

Standards and Certification

This chapter includes information on

Standards organisations
International Electrotechnical Commission (IEC)
CENELEC
European Community
- Distinctive Community Mark
- CE Mark

European Directives
Equipment Categories
Labelling information on certified apparatus

Standards and Certification

Before going any further, it is worth taking a little time to understand the different standards, codes and other regulations which apply to hazardous area electrical apparatus. [1] This will also serve to explain the code letters which appear on the labels of certified equipment and on the certificate for that equipment.

There are three main producers of standards covering hazardous areas and electrical apparatus; the International Electrotechnical Commission (IEC), CENELEC (Europe) and National Standards. Many countries have national standards, produced by their national standards organisation such as BSI (UK) or VDE (Germany) [2] as well as standards produced by other national bodies such as BASEEFA, [3] FM, [4] and the Loss Prevention Council. [5]

IEC Standards

The IEC has a series of standards in the range IEC 79 XX [6] which cover electrical apparatus for use in hazardous areas. Because in some instances the IEC standards have fallen short of giving sufficient detail to enable the standards to be used for testing and certification assessment, other standards have been produced by individual countries and, in recent years, by CENELEC, [7] the electrical standards organisation within Europe. [*] Certainly within Europe, and especially within the EC, the CENELEC Standards have particular importance, and it will be increasingly difficult to market or install electrical apparatus which does not conform to (and in most cases is certified to) these standards.

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* There is, at present, a move to organising IEC certification which will be accepted worldwide, but there are, inevitably, a number of difficulties such as the recognition by each other of different countries' test houses. Although such a scheme will, no doubt, eventually happen, it is likely to take several years before it is organised, and even longer before it is internationally recognised.

CENELEC Standards in Europe

The main standards concerned with the design and certification of electrical equipment for hazardous areas are numbered in the series EN 50 014 to EN 50 039. Until 1994, as far as hazardous area electrical apparatus is concerned, the CENELEC standards only covered the design and certification of the apparatus. [8] That is, the CENELEC Standards were primarily for the apparatus manufacturer, and did not give much, if any information which was of use or interest to the installer or end user of the apparatus. This position will change with the production of two new CENELEC Standards; EN 50 145 covering area classification, and EN 50 154 dealing with installation of electrical equipment in hazardous areas. When these two standards are published (in 1995) there will, for the first time, be a common approach to area classification and installation throughout Europe. [*]

Additionally, the design and certification standards are undergoing a major revision to incorporate the many amendments which have been produced since their original publication and to take account of changes to the technology. This work will result in most of these standards being raised to their second edition. Furthermore, whereas at their first edition, the CENELEC Standards were given individual standard numbers when they were published nationally (such as BSI), at their second edition they will retain the CENELEC number - although this number may be preceded by identifying national letters, for example, the letters BS in the UK. [**]

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* It will be some time before everyone is working to the new standards and minor differences between countries are likely to persist for a while.

** Thus the first edition of EN 50 014 was published by BSI as BS 5501: Part 1. The second edition is published as BS EN 50 014. This move will be welcomed by manufacturers who, for many years have had to try and explain that certification to BS 5501 was in fact a European certification!

The Role of CENELEC within the European Community

The reader will appreciate that, within Europe, the role of the EC (or EU, European Union as it is now becoming known) is becoming more and more important.

For many years there have been various European Directives which refer to the CENELEC Standards and detail **nominated bodies** [*] (approved test houses) which can certify to these standards and authorise the use of the Distinctive Community Mark on certificates and apparatus whose design has been certified.

Figure 3.1 *The Distinctive Community Mark*

This mark is specific to hazardous area electrical apparatus. The directives which called up this mark were not, however, mandatory and, although many EC member countries attempted to follow the requirements of the directives, many were not fully applying the quality assurance requirements which the directives called up as a means of ensuring that manufacturers had sufficient quality assurance procedures to ensure that they would continue to produce products which complied with the certificate. [**] As the EC has gathered momentum, so it wishes to have more formal control, and

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* **Nominated bodies** include BASEEFA, PTB, LCIE etc. A full list appears in Appendix 3.

** It is, of course, only the design which is certified. The product which is sold has not been seen by the nominated body. The purchaser is relying on the manufacturer's QA arrangements to ensure that what he purchases fully complies with the Certificate.

many directives published from 1993 onwards are following what is known as 'the new approach'. This results in more detailed directives and their implementation is mandatory. Products which conform to these directives are usually required to be marked with the European Conformity Mark.

Figure 3.2 *European Conformity Mark*

A directive which relates to equipment and protective systems for use in potentially explosive atmospheres and which falls within this new approach concept was published in April 1994. [9] This directive details the requirements for all equipment intended for use in hazardous areas, both electrical and non-electrical, and requires that all such equipment [*] marketed or installed after 30 June 2003 must fully conform to the directive and must bear the CE mark.

It further details three categories of equipment for surface industry use [10] as follows:

Category 3 equipment is that which is designed to be capable of functioning in conformity with the operating parameters established by the manufacturer and ensuring a normal level of protection. (That is to say it will not give rise to ignition sources under normal operating conditions.)

Category 2 equipment is equipment which continues to achieve

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* It also includes equipment such as 'associated apparatus' which, although not itself located in a hazardous area, has some safety influence on the operation of the hazardous area equipment.

the above security even in the event of frequently occurring disturbances or equipment faults which normally have to be taken into account.

> Category 1 equipment must '*ensure the requisite level of protection, even in the event of rare incidents relating to equipment, and is characterized by means of protection such that:*
>
> *- either, in the event of a failure of one means of protection, at least an independent second means provides the requisite level of protection,*
>
> *- or the requisite level of protection is assured in the event of two faults occurring independently of each other.*'

Although this directive does not detail how or where these categories of equipment can be used, another directive, [11] due for publication in 1995, which is concerned with the user of such equipment makes the connection and states that

> Category 1 is suitable for use in zone 0 (and zone 1 and 2)
> Category 2 is suitable for use in zone 1 (and zone 2)
> Category 3 is suitable for use in zone 2.

This reflects the concept already applied to electrical equipment that if it is normally safe it is suitable for zone 2 (eg Ex n), if it is safe with one fault it is suitable for zone 1 (eg Ex ib), and if it is safe with two faults it is suitable for zone 0 (eg Ex ia).

As equipment becomes available which conforms to the directive, the category number will appear on the apparatus label. The label will also show a letter **G** if it is suitable for gas and vapour hazards, and **D** if it is suitable for dust hazards.

National Standards

Although it is clear that the European Standards (and, especially outside Europe, the IEC Standards) will have an increasingly important role in the certification of apparatus, there are still some national standards which are used. As far as Europe is concerned, as the year 2003 approaches, these standards will gradually cease to be used for new apparatus, although existing apparatus which conforms to national, rather than European standards is likely to remain in use for some considerable time. Thus it is unlikely that the national standards will be withdrawn for many years, although they are unlikely to be used for new designs and certifications.

The evolution of standards in the UK is as follows.

The first standard on intrinsic safety was British Standard BS 1259. This was first published in 1945 and reviewed in 1958. The standard gives very little detail of how intrinsic safety is to be achieved. Certification was then the responsibility of the Factory Inspectorate. [12] BS 1259 gives a different system of definition of gas and vapour hazard classification to that now used. A comparison between the IEC gas groups and those specified in BS 1259 will be found in Appendix 4.

It should be understood that apparatus certified to BS 1259 will refer to the old gas group terminology on its label and great care should be taken to correctly translate this to the currently used terminology before using such apparatus. For example, a popular intrinsically safe megga tester is available which is certified to BS 1259 and is certified as suitable for groups 2a and 2c. Group 2a is ammonia, and group 2c covers some IIA and some IIB hazards. Thus this apparatus is not suitable for use in IEC gas group IIC environments (hydrogen etc.).

The Code of practice for the use and installation of intrinsically safe apparatus was CP 1003: Part 1, published in 1964. This document (again, very simple compared to today's standards) specified the gas

groups in accordance with the early standard for flameproof apparatus (BS 229). Comparison between the gas groups according to BS 229 and the IEC groups can be seen in Appendix 4.

As the popularity of intrinsic safety increased, so it became necessary for improved guidance on the methods which could be employed to achieve the necessary levels of safety. In 1972 BASEEFA [13] published their own document on intrinsic safety; SFA 3012 and followed it in 1976 with a standard specifically aimed at the certification of zener safety barriers (SFA 3004). [14] Both of these documents included the concept of 'ia' and 'ib' classification which was excluded from BS 1259.

Certificates to SFA 3012 and SFA 3004 were termed Certificates of Assurance. SFA 3012 provided for certification of both apparatus and systems. [15]

IEC 79-11 [16] was also produced in 1972 and closely reflected the BASEEFA standard.

1976 saw the publication of the BS 5345 [17] series Code of practice, replacing, for new installations, CP 1003. Part 1 of BS 5345 - general requirements was followed in 1977 by Part 4, covering intrinsic safety.

In 1977 the first edition of EN 50 020 was published and was given the BS number BS 5501: Part 7. [18] This standard, 'Electrical apparatus for potentially explosive atmospheres, part 7, intrinsic safety 'i'', did not include provision for the certification of intrinsically safe systems, and for some time, although apparatus was certified to the CENELEC standard, the system certificate was issued to SFA 3012.

The publication of the CENELEC standard meant that all the CENELEC countries had an equivalent standard and apparatus could be certified to that standard by any CENELEC country's nominated test house. In the UK, this test house was BASEEFA.

Shortly after the publication of the CENELEC standard, the EEC issued various directives calling up the CENELEC standards, listing the test houses of EEC member countries and terming them 'nominated bodies' and stating that apparatus certified to the CENELEC standards by an EEC nominated body could bear the Distinctive Community Mark. Certificates were now termed Certificates of Conformity as opposed to Certificates of Assurance.

In 1981 CENELEC issued the intrinsic safety systems standard as EN 50 039. This was published as a British Standard in the UK in 1982 (BS 5501: Part 9).

Since the publication of the CENELEC standards, the position has remained relatively stable. As would be expected, a number of amendments have been issued to the standards, clarifying or expanding particular points and these, together with additional explanation have now been incorporated into the second edition of the CENELEC standards. However, at present there is no second edition of EN 50 039, the systems standard. [*]

Labels, Marks and Codes for Electrical Apparatus used in Hazardous Areas

Electrical apparatus intended for use in hazardous areas is marked with the letters Ex, followed by one or more letters which denote the method(s) of protection employed.

If the apparatus conforms to one of the CENELEC European Standards, then the letters Ex will be preceded with an additional E, giving **EEx**.

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* Because not all the CENELEC standards have been updated to their second edition, both the first and second editions of the general part of the standard, EN 50 014 will remain current for some time. When purchasing standards take care to order the appropriate edition.

The code also indicates the most hazardous gas group in which the apparatus may be used; IIA, IIB or IIC [*] and the applicable temperature class, T1, T2, T3, T4, T5, or T6.[19] Thus the overall code appears as follows:

EEx ia IIC T6

Maximum surface temperature of apparatus (T6 = 85 °C)

Most onerous gas group in which apparatus may be used

Method of protection ia

Explosion protected by:

Conforming to European (CENELEC) Standard

Figure 3.3 *Code on Apparatus*

Examples of typical label information of intrinsically safe and associated apparatus are given on the following pages, and it will be seen that the label information includes data which is of significant interest to the user of the apparatus, since it informs the installer and user:

- □ where the apparatus can be used by indicating the gas group and, via the method of protection, the zone

  intrinsic safety 'ib' is suitable for zones 1 and 2. Intrinsic safety 'ia' is suitable for zones 0, 1 and 2.

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* For some methods of protection, only the main surface industry group notification II is marked, signifying acceptability for all sub-groups within group II. However, this practice is not adopted for intrinsic safety.

- if the apparatus is associated apparatus and thus only suitable for installation in a non-hazardous area

  If the code letters EEx (or Ex) ia (or ib) are enclosed in square brackets thus: [EEx ia] IIC, then the apparatus is associated apparatus. In the example shown, it is suitable for connection to appropriate apparatus which may be installed in gas group IIA or IIB or IIC.

- where more details may be found if necessary, since it gives the certificate number
- by the use of the letter **U** at the end of the certificate number, indicating that the apparatus is only *component certified*
- by the use of the letter **X** at the end of the certificate number indicating that there are special conditions of installation or use [*]
- by various additional codes [**] giving details of maximum input and output parameters.

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* In the past, the letter **B** has been used with some nationally certified apparatus to indicate the same meaning as X.

** These will be explained in detail later in the book.

Figure 3.4 *Label Information for an Intrinsically Safe Transmitter intended for use in Zones 1 or 2 and any Gas Group. The apparatus has been certified by BASEEFA to National Standards.*

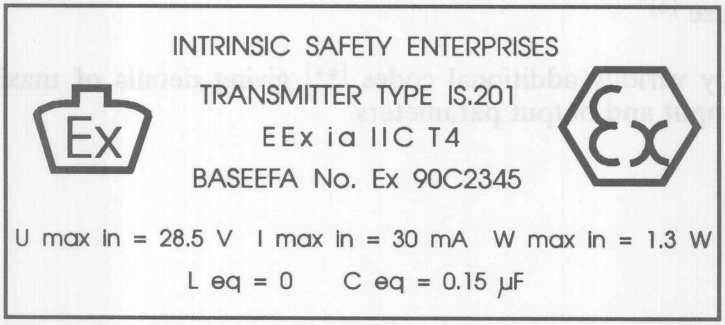

Figure 3.5 *Label Information for an Intrinsically Safe Transmitter which has been Certified by BASEEFA to the First Edition of the European Standards. The Transmitter may be used in Zones 0, 1 or 2 and any Gas Group.*

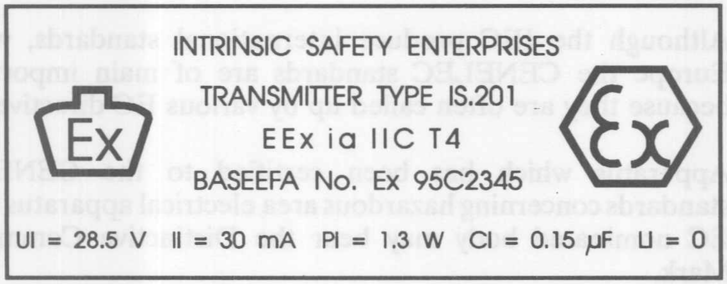

Figure 3.6 *Label Information for an Intrinsically Safe Transmitter (as Figure 3.5) which has been Certified by BASEEFA to the Second Edition of the European Standards. The Transmitter may be used in Zones 0, 1 or 2 and any Gas Group.*

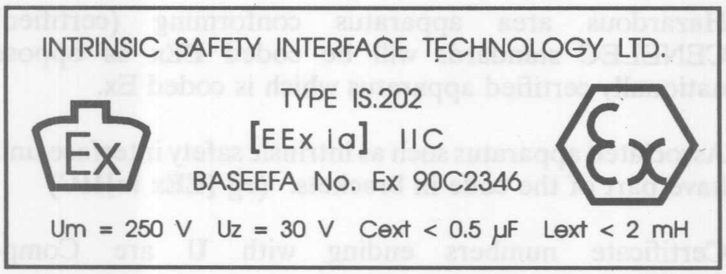

Figure 3.7 *Label Information for Associated Apparatus, Certified to the First Edition of the European Standards, and whose output may be Connected to Suitable Apparatus in Zone 0, 1 or 2 and any Gas Group. The Associated Apparatus itself is not intended for use in the Hazardous Area.*

(The same apparatus, certified to the Second Edition of EN 50 020 would show Uo instead of Uz, Co instead of Cext, Lo instead of Lext. Additionally, Io and Po may be shown.)

SUMMARY

- Although the IEC produce international standards, within Europe the CENELEC standards are of main importance because they are often called up by various EC directives.

- Apparatus which has been certified to the CENELEC standards concerning hazardous area electrical apparatus by an EC nominated body may bear the Distinctive Community Mark.

- Over the next few years the European Conformity mark will also be applicable to hazardous area electrical apparatus.

- Equipment categories (defined by European Directive 94/9/EC) determine the zone of installation for the apparatus.

- Hazardous area apparatus conforming (certified) to CENELEC standards will be coded **EEx** as opposed to nationally certified apparatus which is coded Ex.

- Associated apparatus such as intrinsic safety interface units will have part of the code in brackets. (eg **[EEx ia]IIC**)

- Certificate numbers ending with **U** are Component Certificates.

- Apparatus where the certificate number ends with **X** have special conditions of installation or use.

NOTES AND REFERENCES

1. This subject is covered in more detail in the companion book 'Electrical Apparatus and Hazardous Areas' by the same author.

2. VDE. Verband Deutscher Electrotechniker. The German standards organisation.

3. BASEEFA. The British Approvals Service for Electrical Equipment in Flammable Atmospheres, has, from time to time published its own standards for certification purposes. These standards have the prefix SFA. For example SFA 3012 on intrinsic safety.

4. FM. Factory Mutual. One of two main testing organisations in the USA.

5. The Loss Prevention Council is primarily concerned with fire precautions and publishes its own standards on the subject.

6. For a full list of IEC Standards relating to hazardous areas and electrical apparatus, see Appendix 4.

7. CENELEC. The Committee of European Electrical Standardisation.

8. With the possible exception of a systems standard for intrinsic safety; EN 50 039. This will be explained in more detail in later chapters.

9. Directive 94/9/EC of the European Parliament and the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres.

10. There are additional categories for mining use; M1, M2 and M3 with similar meanings.

11. The directive concerning minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres will be published during 1995.

12. REDDING, R.J. Intrinsic Safety, McGraw-Hill, London 1971. This book includes an interesting chapter on the history of intrinsic safety and certification.

13. BASEEFA. British Approvals Service for Electrical Equipment in Flammable Atmospheres. BASEEFA are the surface industry arm of EECS; the Electrical Equipment Certification Service at Buxton, Derbyshire. The mining arm is MECS; Mining Equipment Certification Service. Both are based at the same site. EECS is part of the UK government's Health and Safety Executive. For address see Appendix 3.

14. SFA 3004. BASEEFA specification for shunt diode safety barriers.

15. Systems normally comprise one or more items of intrinsically safe 'approved' apparatus or simple apparatus located within the hazardous area, connected to associated apparatus - typically a zener barrier, located in the non-hazardous area.

16. IEC 79-11. Electrical apparatus for explosive gas atmospheres. Part 11: Construction and test of intrinsically safe and associated apparatus.

17. BS 5345. British Standard Code of practice for selection, installation and maintenance of electrical apparatus for use on potentially explosive atmospheres (other than mining applications or explosives processing and manufacture) Part 1, General requirements. Part 4, Installation and maintenance requirements for electrical apparatus with type of protection 'i'. Intrinsically safe electrical apparatus and systems.

18. BS 5501 Parts 1 to 9 equates to EN 50 014 etc.
See Appendix 4.

19. Temperature classes normally relate to an maximum ambient temperature of 40°C. If a higher (or lower) maximum ambient temperature applies, then this is normally noted after the T-Class. For example:

EEx ia IIC T6 (Tamb 60°C)

indicates apparatus which will still meet the stated T-Class (T6 means a maximum surface temperature of 85°C) *even if the ambient temperature is as high as 60°C.*

CHAPTER 4

Intrinsic Safety
Concept and Principle

This chapter includes information on
Minimum ignition energy Factor of safety Fault conditions for intrinsic safety assessment Categories of intrinsic safety 'ia' and 'ib' Associated apparatus - the safety interface Zener barrier

Intrinsic Safety - Concept and Principle

In the previous chapters, the general terminology of hazardous areas and the methods of protection other than intrinsic safety have been summarised. If the other methods of protection are compared one with another, it will be appreciated that in all cases the main safety criteria are in fact mechanical. [*] The alternative, and the principle on which intrinsic safety is based, is that of controlling or limiting the electrical energy to levels which are less than the minimum ignition energy of the flammable hazard.

The idea of intrinsic safety, which is, of course, only applicable to very low powered circuits such as instrumentation, is to maintain, even under fault conditions, a state such that the electrical power in the circuit is not sufficient to cause ignition *even if the circuit gives rise to arcs and sparks*.

Once that state has been achieved, then it is no longer necessary to rely on mechanical protection such as flameproof or pressurized enclosures. So intrinsic safety is concerned with low power circuits and keeping the circuits that way even under fault conditions.

Research work, using spark test apparatus, has enabled the minimum levels at which sparks can cause ignition of various hazards to be established. The results are available in graphical form and are published in the design standards such as EN 50 020 so that designers can produce circuits which meet the essential criteria of intrinsic safety. There are published minimum ignition curves for resistive, capacitive and inductive circuits, and some of the curves from the second edition of EN 50 020 are reproduced in

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* You may feel that this statement does not really hold true for n-type and increased safety protection, but even with these methods there is a requirement for IP54 protection and impact strength tests.

Appendix 1. The curve for resistive circuits is also shown in this chapter for ease of reference. [*]

Faults and Factors of Safety

If the methods of protection Ex n and Ex e are compared from the information in Chapter 2, it will be apparent that the main difference between the two concepts is that Ex n is only safe under normal conditions, whereas Ex e is safe under normal conditions and under one (any one) fault condition. Ex n is only suitable for zone 2, whereas Ex e may be used in zones 1 and 2. This principle is, in fact, utilised in all the methods of protection [**] and may be extended to cover zone 0 applications as well to give the following position.

Protection suitable for..	must be safe under ..
Zone 2	normal operation
Zone 1	normal operation plus one fault
Zone 0	normal operation plus two (independent) faults

Table 4.1 *Fault Counts and Zone of Use*

There are actually two categories of intrinsic safety: 'ia' and 'ib'.

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* The published minimum ignition curves do not mean that it is never necessary to test circuits for certification under laboratory conditions, although quite often the circuit can be fully assessed from the curves. When combinations of capacitors and resistors mean that possible stored energy cannot be directly assessed from the curves, samples of the circuit being evaluated will be subjected to spark test assessment.

** Although it is not always obvious without detailed analysis.

The distinction between the two categories relates to their continued intrinsic safety under fault conditions. [1] The two categories of intrinsic safety are defined in the IEC and European Standards as follows.

Category 'ia'

Electrical apparatus of category 'ia' shall be incapable of causing ignition in normal operation, with a single fault and with any combination of two faults applied.

Category 'ib'

Electrical apparatus of category 'ib' shall be incapable of causing ignition in normal operation and with a single fault applied.

Thus intrinsic safety 'ia' considers two fault conditions, whereas intrinsic safety 'ib' only considers one fault condition.

If this position is compared to the earlier consideration of Ex e and Ex n apparatus, and to the foregoing table of fault conditions, it will be appreciated that intrinsic safety 'ib' is suitable for application in zones 1 and 2, whereas intrinsic safety 'ia' is suitable for application in zones 0, 1 and 2. [*]

If the resistive ignition curves, reproduced in Figure 4.1 are examined, it would be reasonable to assume that a purely resistive circuit (that is, a circuit containing no capacitance or inductance) operating at say 30 volts, could have a current of 140 mA and be within intrinsic safety limits.

---

* Intrinsic safety 'ia' is, in fact, the safest of all the methods of protection, and (with the possible exception of nationally certified Ex s apparatus stating zone 0 use) is the only method of protection which is suitable for zone 0 application. As will be seen, however, intrinsic safety enjoys some considerable latitude with installation conditions which is not applicable to any other method of protection.

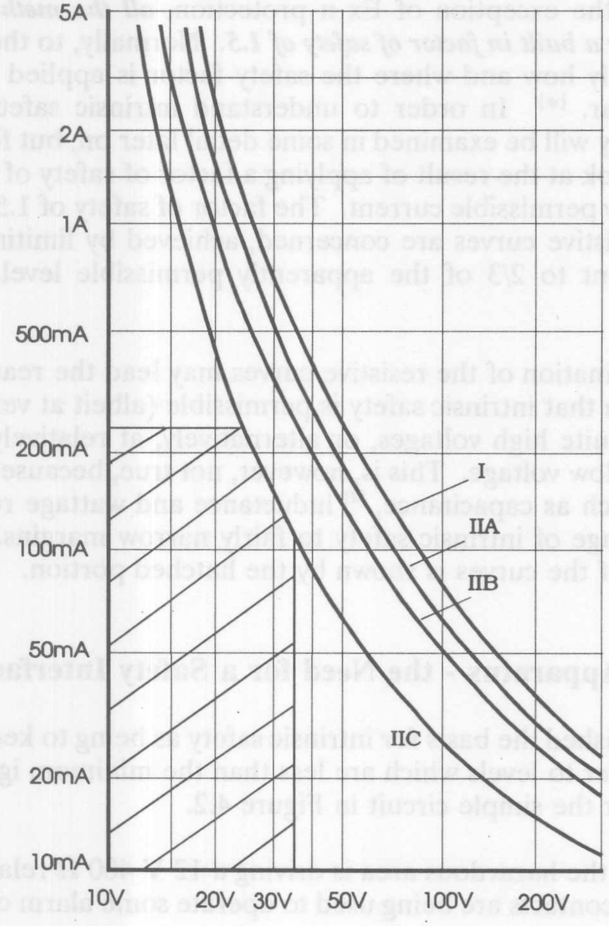

Figure 4.1 *Minimum Ignition Curves (Resistive Circuits)*

(The hatched area shows the usable portion. Outside this area other constraints take effect. See Chapter 13)

This position would, however, only give a factor of safety of unity, but since the whole subject is indeed to do with safety, it would

seem reasonable that some greater safety factor should be applied. In fact, with the exception of Ex n protection, ***all the methods of protection have a built in factor of safety of 1.5***. Normally, to the user at least, exactly how and where the safety factor is applied is not especially clear. [*] In order to understand intrinsic safety this factor of safety will be examined in some detail later on, but for the time being, look at the result of applying a factor of safety of 1.5 to the apparently permissible current. The factor of safety of 1.5 is, as far as the resistive curves are concerned, achieved by limiting the allowed current to 2/3 of the apparently permissible level, thus giving 93 mA.

Further examination of the resistive curves may lead the reader to the conclusion that intrinsic safety is permissible (albeit at very low currents) at quite high voltages, or alternatively, at relatively high currents with low voltage. This is, however, not true, because other constraints such as capacitance, [2] inductance and wattage restrict the usable range of intrinsic safety to fairly narrow margins. The 'useful area' of the curves is shown by the hatched portion.

Associated Apparatus - the Need for a Safety Interface

Having established the basis for intrinsic safety as being to keep the electrical power to levels which are less than the minimum ignition level, consider the simple circuit in Figure 4.2.

The switch in the hazardous area is driving a 12 V 400 Ω relay coil, and the relay contacts are being used to operate some alarm circuit.

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* Indeed, the end user of hazardous area electrical apparatus does not really need to understand where and how the safety factor is applied - it has been done for him by the apparatus manufacturer and that is part of what he is paying for when he buys certified apparatus. The end user can sleep soundly in the knowledge that, *providing the apparatus is correctly installed and maintained and installed in the applicable zone* it is very safe indeed.

The relay coil circuit is powered from a 12 volt dc source, which is, in turn, generated from a modular mains power supply. Thus, under normal operating conditions the current in the relay coil and hazardous area switch circuit will be 12/400 = 30 mA. A glance at the resistive curves will show that this level is well within the boundaries of intrinsic safety. Even allowing for the factor of safety of 1.5 and thus obtaining a current of 45 mA, the conditions still appear to be met. However, there are several aspects which need consideration before the intrinsic safety of the circuit can be properly proclaimed.

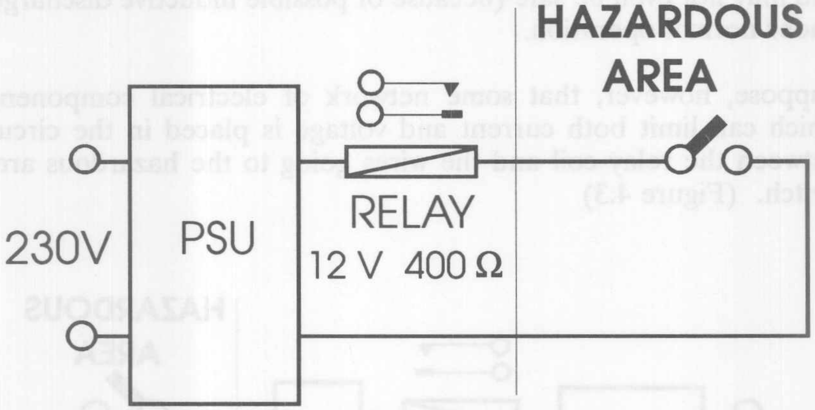

Figure 4.2 *A Simple Intrinsically Safe Circuit - or is it?*

Firstly, the relay coil will be inductive. Although the coil is located in the non-hazardous area, any stored energy giving rise to a back emf discharge spark will, of course, occur at the switch in the hazardous area. [*] Is the relay intrinsically safe? Who has

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* It was a condition like this which led to the major mining disaster at Senygenhyd colliery in October 1913. In this case, the inductive spark was caused by a bell coil in a simple signalling system. It was as a result of this accident, and the subsequent enquiry that the need for a safety interface became apparent (but it took many years before it was eventually developed).

assessed its inductance to the intrinsic safety curves?

Secondly, what will happen if the power supply fails? Presumably, under worst case conditions, mains voltage of say 230 V ac could be applied directly to the circuit containing the switch in the hazardous area. Unlikely? Well perhaps so, but is it a reasonable risk to take with a hazardous area? Certainly not. Indeed, we have already seen that even an 'ib' circuit needs to be safe both in normal operation and under one fault condition. This circuit is certainly not safe under the fault condition of mains power breakthrough, and may not even be safe (because of possible inductive discharge) under normal operation.

Suppose, however, that some network of electrical components which can limit both current and voltage is placed in the circuit between the relay coil and the wires going to the hazardous area switch. (Figure 4.3)

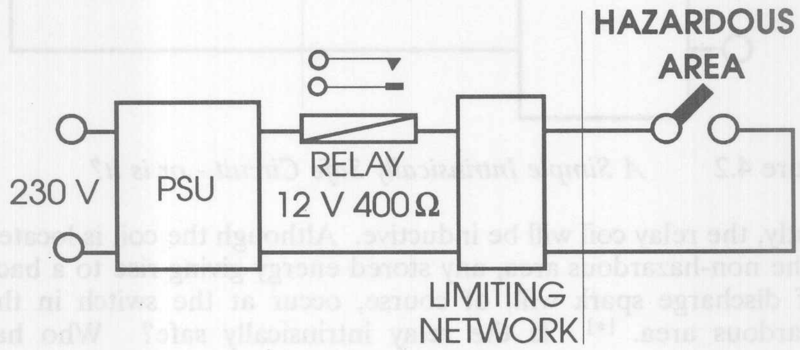

Figure 4.3 *The idea of a 'Safety Interface'*

Further, suppose that the levels of current and voltage limiting are such that the output into the hazardous area cannot exceed the level of 12 volts at 45 mA even under fault conditions including a major failure causing mains breakthrough of the power supply.

Now the position is entirely different. If the safety network can be shown to be fail safe with one fault, then intrinsic safety 'ib' has been achieved. If it can be shown to be safe even with two faults, then intrinsic safety 'ia' has been achieved. This network is given a special name. It is **associated apparatus**. Associated apparatus is apparatus on which intrinsic safety depends, but it is not (or at least not completely) intrinsically safe itself. Normally, associated apparatus is located in the non-hazardous area, as close as practicable to the boundary of the hazardous area. The output terminals of the associated apparatus are connected directly to the intrinsically safe circuit.

There are many kinds of associated apparatus - interface units designed for use with intrinsically safe circuits. Normally, the associated apparatus is a separate stand alone item, [*] but it may be incorporated into the non-hazardous area apparatus. Some of the simplest associated apparatus are zener safety barriers. [**]

Because associated apparatus is fundamental to the protection method of intrinsic safety, it is awarded a special code so that it is easily recognisable. Quite simply, associated apparatus has its intrinsic safety code surrounded by square brackets. Thus a piece of apparatus bearing the code:

[EEx ia]IIC

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* On large installations, there may be racks and racks of interface units serving all the intrinsically safe circuits on the plant. Such racks or cabinets of associated apparatus are often located adjacent to the control room.

** Also known as 'shunt zener diode safety barriers' or just 'zener barriers' for short! The term zener barrier is, however, very specific, and should never be loosely used to refer to other types of intrinsically safe interface such as galvanic isolators. Galvanic isolators have a similar safety function to zener barriers and are also associated apparatus; they will be explained later on.

indicates an item of associated apparatus whose output terminals may be connected to an intrinsically safe circuit which is located in any gas group (IIA, IIB or IIC) and which circuit is in any zone (0, 1 or 2). The associated apparatus itself, of course, is not suitable for location in the hazardous area.

Notice also that the associated apparatus does not have a T-Class specified in the code. It does not need one, because it is not going to be located in the hazardous area, and so, however hot it gets, it cannot ignite the hazard.

Because the interface unit is so important to intrinsic safety, and because it conveniently serves to explain in more detail the principal safety criteria of this method of protection, the next chapter examines the zener safety barrier - the most commonly used and simplest interface unit - in detail.

SUMMARY

- □ Zone 0 apparatus must be safe even with two (countable) faults. Intrinsic safety category 'ia' achieves this level of safety.
- □ Zone 1 apparatus must be safe even with one (countable) fault. Intrinsic safety 'ib' achieves this level of safety.
- □ Intrinsic safety (both 'ib' and 'ia') has a 'built-in' factor of safety of 1.5.
- □ Intrinsically safe circuits need a safety interface. This is called **associated apparatus** and is normally located in the non-hazardous area.
- □ Associated apparatus is easily identified by its label. The safety code will be partially enclosed in brackets, for example **[EEx ia]IIC**.

NOTES AND REFERENCES

1. In the USA, under the National Electrical Code and other USA national standards, there is only one category of intrinsic safety. Although specified in a slightly different way, it is essentially the same as intrinsic safety 'ia'.

2. Examination of the capacitive and inductive curves in Appendix 1 will serve to demonstrate this. Remember, capacitive and inductive values need a factor of safety too. With the capacitive curves this is applied to voltage, and with the inductive curves, to current. Even interconnecting cables will have some capacitive and inductive properties, and at higher voltages or currents respectively, even this small amount becomes significant. These aspects will be explored in more detail later in the book.

CHAPTER 5

Associated Apparatus (1) The Safety Interface

This chapter includes information on
Why intrinsic safety needs a safety interface Concept of fault conditions: countable faults Categories of intrinsic safety 'ia' and 'ib' Infallible components Ignition curves (resistive) Apparatus connected to output of associated apparatus

Associated Apparatus - the Safety Interface

In the last chapter the main principles of intrinsic safety were explained, and it was shown that, in order to maintain an intrinsically safe condition under fault conditions, there needed to be some safety interface. This apparatus is known as 'associated apparatus' and is normally located in the non-hazardous area.

There are several different types of safety interface unit and some perform just the basic associated apparatus task whilst others, in addition to the associated apparatus function, also perform signal conditioning and various other operations.

Perhaps the simplest form of associated apparatus is the zener safety barrier. This simple circuit, which was developed in the early 1960's [*] revolutionised the use and application of intrinsic safety which had previously been mainly restricted to the mining industry and used for simple signalling systems. Apart from assisting in the understanding of intrinsically safe circuit loops later in the book, a detailed explanation of the zener safety barrier will serve to explain the main design concepts of intrinsic safety. [**]

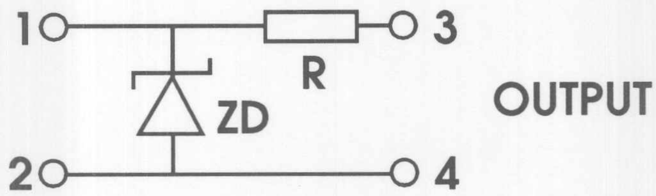

Figure 5.1 *Essential Elements of Interface*

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* The first zener barrier, known as the Type 1 was developed by Chris Towle in 1964.

** Other forms of associated apparatus such as galvanic isolators are examined in Chapter 11.

Examination of Figure 5.1 will show that the output from terminals 3 and 4 will be limited as follows:

- the maximum current which can be drawn (which will be under short circuit conditions) will be defined from Ohm's Law by the current which can flow through the resistor R at the clamping voltage of the zener diode ZD. [1]

  Thus maximum output current

  $\mathbf{I = V_{ZD}/R}$

  For example, if the value of R is 300 Ω and the value of ZD is 28 V, then the maximum short circuit current will be 28/300 = 93 mA. [2] This maximum output current, using the worst case tolerances for the zener diode and the resistor, is defined as I_o or $I_{max\ out}$. This will be marked on the label of the associated apparatus.

- the maximum open circuit voltage which can appear at terminals 3 and 4 will be limited to the zener voltage of ZD. This maximum output voltage, taking account of zener diode tolerance, is defined as U_o or U_z. This will be marked on the label of the associated apparatus.

- the maximum power which can be usefully employed from the output terminals 3 and 4 will be realised if a load resistor $\mathbf{R_L}$, *of resistance equal to the resistor R* is connected to the output terminals.

  Thus, for the example used above, if a load of resistance = 300 Ω were connected to terminals 3 and 4, the power dissipated in the load would be defined by:

  Current in circuit $= ZD/(R + R_L)$

  $= 46.7$ mA

$$\text{Power in load resistor} = I^2.R_L$$

$$= 0.0467^2 \times 300$$

$$= 0.65 \text{ watts}$$

In fact, the output power for the 28 V 300 Ω used will vary according to load as indicated in Figure 5.2.

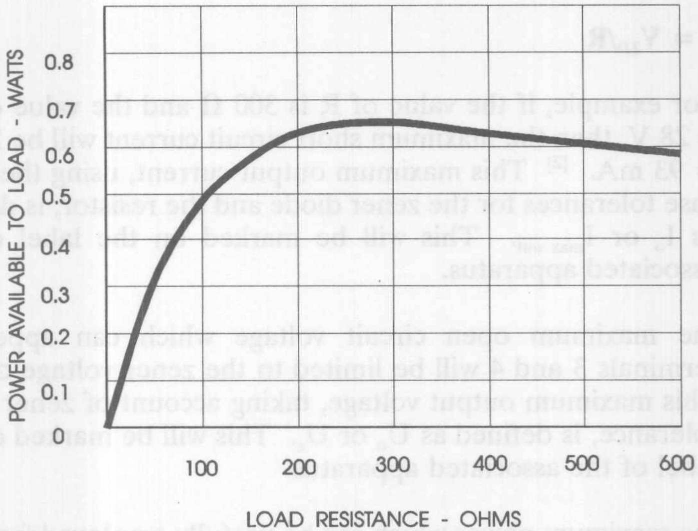

Figure 5.2 *Maximum Power Dissipated in Varying Loads for the Circuit shown in Figure 5.1*

It will be appreciated that these conditions hold true irrespective of the input conditions at terminals 1 and 2, providing the zener diode is not subjected to a power dissipation greater than that for which it is rated.

This results in a slight problem, since the input conditions are not known. The interface device is used to take care of fault conditions which occur in the non-hazardous area, and exactly what these fault

conditions will be are not known. This problem is addressed by the standards for intrinsic safety by two criteria.

Firstly, the maximum voltage which can safely be connected to terminals 1 and 2 *under worst case fault conditions* is required to be defined (as part of the certification procedure) and marked on the label for the associated apparatus. The code used to indicate the maximum input voltage is $\mathbf{U_m}$. [*]

Secondly, if the interface is to be usable in all normal situations, and is not to have restricted usage conditions, it must be able to withstand **without failing to an unsafe condition** a prospective current of 1500 A.[3] Clearly, to use a 28 volt zener diode which was rated for 1500 A, and could withstand this current at voltages up to mains voltage would mean using a very large zener diode, since, apart from other considerations, the power rating for the diode would be defined by the zener voltage (28 V) x 1500. (42000 watts!)

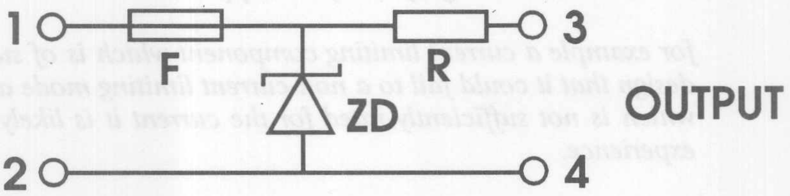

Figure 5.3 *Showing the Addition of a Suitable Fuse in the Interface*

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* It must be understood that the value of U_m is not the same as the maximum intended operating voltage, but is rather the maximum voltage at which the interface will still correctly perform its intended safety function. Commonly, the value of U_m is that of mains voltage under worst case conditions (265 V), but the zener diode will be rated at much less than this, for example 28 volts, and if mains voltage is applied it may cause the circuit to fail - although, as will be shown, it will fail safe.

The circuit thus needs some current limiting device on the input side, and as far as zener barriers are concerned, this device is normally a fuse [4] which is capable of withstanding a prospective current of 1500 A. Such fuses are normally of ceramic, sand-filled construction. [5] The circuit shown in Figure 5.1 thus becomes modified as shown in Figure 5.3

At this stage some further explanation of fault conditions in intrinsically safe circuits is necessary.

Faults in Intrinsically Safe Circuits

In order to understand the way in which fault conditions are assessed in intrinsic safety it is necessary to appreciate that failures (of a circuit to an unsafe condition) can be categorised into three groups:

- those which are highly likely to happen

  for example a current limiting component which is of such design that it could fail to a non-current limiting mode and which is not sufficiently rated for the current it is likely to experience.

  Any intrinsic safety assessment will assume that such a fault has happened.

- those which are extremely unlikely to happen

  for example that the standard 'mains' voltage supply will, without notice, change to 1000 V.

  Such faults are ignored for the purposes of intrinsic safety evaluation.

- those faults which, whilst reasonably unlikely, are not sufficiently remote to be discounted altogether

  for example although the zener diode in the circuit shown in Figure 5.3 has been rated correctly, according to its zener voltage and the protective fuse, if the zener diode fails will it fail short circuit or open circuit? If it fails short circuit, then there will be no output at terminals 3 and 4 and this would be a fail safe condition. But is it possible to be sure of this failure mode? In fact, although it is likely that zener diodes will fail to a short circuit condition, this cannot be guaranteed. Thus the possibility of the zener diode failing to an open circuit condition - such that it did not provide any voltage limiting at all - needs to be considered.

  Such faults are **countable faults**.

Mention has already been made of two categories of intrinsic safety; 'ia' and 'ib'. The distinction between the two categories is dependent on how they respond under varying fault conditions.

Categories of Intrinsic Safety 'ia' and 'ib'

The exact definition of 'ia' and 'ib' varies slightly from standard to standard, but the meaning is always the same. The definitions used here are from the second edition of EN 50 020.

Intrinsic safety **'ib'** is achieved if, under the stated maximum input conditions, the intrinsically safe circuits are not capable of causing ignition

a) in normal operation and with the application of those non-countable faults which give the most onerous condition

and

b) in normal operation and with the application of one countable fault [*] plus the application of those non-countable faults [**] which give the most onerous condition.

Thus, intrinsic safety 'ib' is safe under normal operation and will remain safe even with one fault.

Intrinsic safety 'ia' is achieved if, under the stated maximum input conditions, the intrinsically safe circuits are not capable of causing ignition

a) in normal operation and with the application of those non-countable faults which give the most onerous condition

and

b) in normal operation and with the application of one countable fault plus the application of those non-countable faults which give the most onerous condition

and

c) in normal operation and with the application of two countable faults plus those non-countable faults which

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* The countable fault will be selected by whoever is assessing the circuit, normally the certification body. They will, quite rightly and as required by the Standard, apply the most disastrous countable fault they can conceive. They may try several different faults on different tests to establish the worst fault, but they will only apply one at a time.

** The non-countable faults may be the same faults or different faults from those in a).

give the most onerous condition.

Thus, **intrinsic safety 'ia' is safe under normal operation and will remain safe even with two faults.**

In the case of both 'ia' and 'ib' the safety on the non-countable and first countable fault must be achieved whilst maintaining a factor of safety of 1.5. The requirement for this safety factor has been explained in Chapter 4.

Reverting to the consideration of the interface circuit under consideration, it will be seen (Figure 5.4) that if the zener diode fails to an open circuit condition, then the output has no protection against excessive input voltage. The failure of the zener diode to this state is regarded as a countable fault.

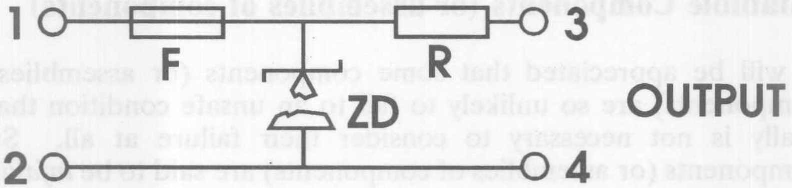

Figure 5.4 *Showing that an Open Circuit Failure of the Zener leads to an Unprotected Output Voltage*

This position may be remedied by the addition of a second zener diode, selected and rated in the same way as that used for the first zener diode. This will result in the circuit shown in Figure 5.5, and it will now be seen that either zener diode can be failed to an open circuit condition, but the output will still be limited to the desired level; in this case to a maximum open circuit voltage of 28 V and a maximum short circuit current of 93 mA.

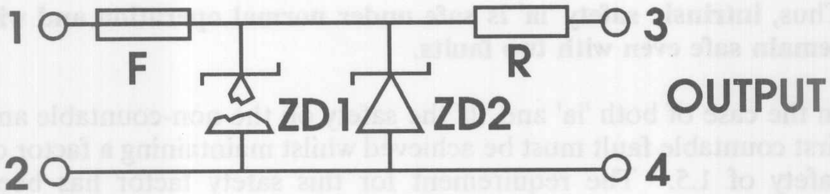

Figure 5.5 *Showing the addition of a Second Zener Diode which will enable the desired Maximum Output Conditions to be maintained even if One Zener Diode fails to Open Circuit*

Infallible Components (or assemblies of components)

It will be appreciated that some components (or assemblies of components) are so unlikely to fail to an unsafe condition that it really is not necessary to consider their failure at all. Such components (or assemblies of components) are said to be *infallible*.

One such example of an infallible component is a suitably rated wire wound or metal film resistor used for current limiting purposes. It is a well established fact that, used within its intended rating, if such a resistor fails, it will fail to a higher resistive (normally open circuit) mode. This is, as far as current limiting is concerned, a safe form of failure, and thus the resistor may be regarded as a fail-safe device.

Within intrinsic safety design, much use is made of such infallible components. The definition of an infallible component (or infallible assembly of components) in the second edition of EN 50 020 is:

a component or assembly that is not likely to become defective, in service or in storage, in such a manner as to invalidate intrinsic safety.

In the circuit shown in Figure 5.5, the resistor will be a wire wound or metal film resistor, operating, in worst case conditions at no more than 2/3 of its power rating. (The safety factor of 1.5.) The resistor is therefore classed as infallible, and failure conditions for this component do not need to be considered.

Since the fuse, if it fails, will also fail to an open circuit condition, the only component failures [*] which can lead to countable faults in this circuit are failures of ZD1 and ZD2.

Thus, the circuit shown in Figure 5.5 meets the design criteria for intrinsic safety 'ib'. Assessment of the output of the interface against the intrinsic safety curves will be considered later in this chapter.

With the exception of some portable apparatus which is unlikely to ever be required in a zone 0 area, and some specialised circuits intended for particular applications, it is normal for designers of intrinsically safe circuits to design for intrinsic safety category 'ia'. This means that the circuit [**] can be in any zone; 0, 1 or 2.

Although it may be argued that for many applications, this is unnecessary overkill, it does mean, especially with conventional interfaces, (where the manufacturer does not know, or need to

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* Failures of electrical connections, printed circuit board tracks etc. must also be considered. For the moment, assume that this has been done and is successful. For those readers interested in such matters, which are really the concern of the designer of intrinsically safe apparatus, refer to Chapter 13. For the purposes of the explanation at this stage, only component failures will be considered.

** Or, in the case of associated apparatus such as the zener barrier currently being examined, the output of the circuit.

know, the application) that the interface will be suitable for the intended application regardless of the zone of installation of the hazardous area apparatus.

In order to make the circuit examined meet the requirements for intrinsic safety 'ia' two countable faults must be considered. Clearly, the worst case second countable fault will assume the second zener diode fails to an open circuit condition. This leads again to a position where there is no voltage limitation on the circuit output. (Figure 5.6) [6]

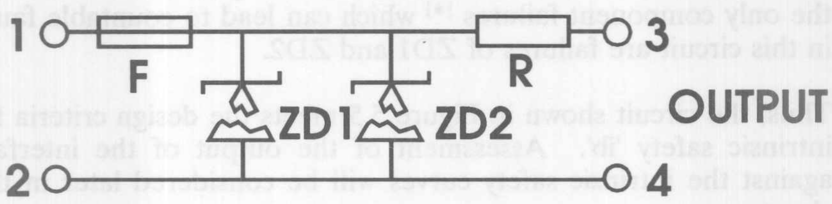

Figure 5.6 *Showing how a Second Fault, applied for consideration of Category 'ia' again renders the Interface Unsafe*

The remedy is a simple one; add a further zener diode to the circuit. This results in the circuit shown in Figure 5.7 which is the final circuit for a basic zener barrier.

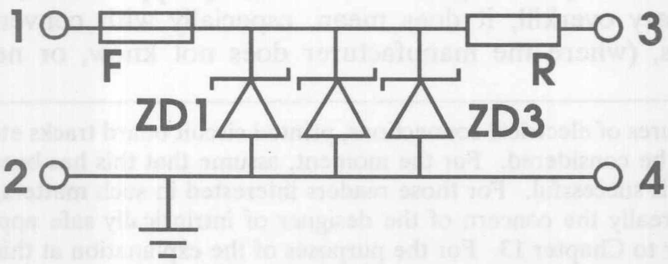

Figure 5.7 *Simple 'ia' Zener Barrier with Three Zener Diodes to Achieve the Desired Safety under Two Countable Fault Conditions.*

The terminal numbering shown is that conventionally used, and it will be seen that the line connecting terminals 2 and 4 is shown to be connected to 'earth'. This aspect has no immediate bearing on the basic explanation of this chapter, but will be considered in more detail in later chapters.

It should also be appreciated that the zener barrier circuit discussed is 'polarity conscious'. The barrier's polarity is the intended polarity of the electrical signal on the non-earthed line with respect to earth. Thus, if the circuit is negative earthed, then a positive polarity barrier (as has been described) will be required.

If the barrier is used for the wrong polarity, for example if the positive barrier is used with a signal that is negative with respect to earth, there is a risk of blowing the fuse, since the zener diode will conduct in the forward direction. (Figure 5.8)

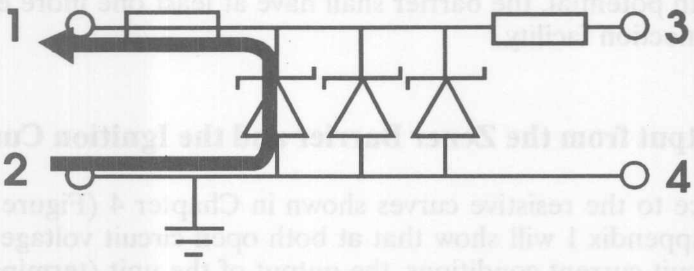

Figure 5.8 *Showing the Current Path which may cause the Internal Fuse to Rupture if the Barrier is Subjected to the Wrong Polarity*

Constructional Considerations

In the main, the constructional considerations for intrinsic safety design will be reviewed in Chapter 13. As far as the zener barrier is concerned, suffice it to summarise at present that the following

mechanical conditions must also be achieved. (Specified in EN 50 020)

- The circuit of the zener barrier must be protected against access to prevent repair or replacement of components upon which intrinsic safety depends. In the circuit shown, all the components fall within this description. This protection is normally achieved by encapsulating the unit in epoxy resin. [7]

- The construction shall be such that, when groups of zener barriers are mounted together, any incorrect mounting is obvious. This is normally achieved by making the physical design asymmetrical in shape or colour, or both, in relation to the mounting mechanism.

- In addition to any circuit connection facility which may be at earth potential, the barrier shall have at least one more earth connection facility.

The Output from the Zener Barrier and the Ignition Curves

Reference to the resistive curves shown in Chapter 4 (Figure 4.1) and in Appendix 1 will show that at both open circuit voltage and short circuit current conditions, the output of the unit (terminals 3 and 4) will be well within the limits required for intrinsic safety *for any gas group - IIA, IIB, or IIC*, including the necessary factor of safety of 1.5. The analysis is as follows.

Enter the curve at 28 volts. For gas group IIC the indicated maximum permissible current is 180 mA. Apply a factor of safety of 1.5 to this value. This gives 180/1.5 = 120 mA. The maximum short circuit current has already been shown to be 93 mA; well within the permitted maximum value.

Connection of Apparatus to the output of the Zener Barrier

The output from the zener barrier has been considered and shown to be within the limits imposed by the resistive curve. This means that, if a pair of wires is connected to terminals 3 and 4, and the wires taken into the hazardous area, the wires may be joined together and disconnected at will, *regardless of what is happening to, or connected to terminals 1 and 2*, and any spark which occurs at the join or break will not be capable of causing ignition. (Figure 5.9)

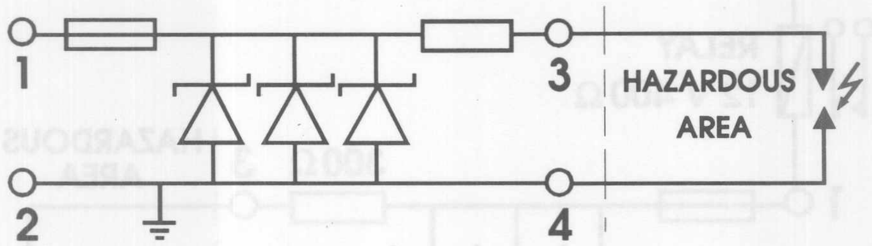

Figure 5.9 *Showing how the Output of the Zener Barrier will lead to an Intrinsically Safe Circuit in the Hazardous Area*

Clearly, it would be unusual to have a situation [*] where the wires were being sparked together, but if the concept is extended a little further, it will be seen that, from an intrinsic safety viewpoint, the result is exactly the same if the pair of wires have a switch on the end. This leads to a complete solution to the position considered at the end of Chapter 4, and gives the result shown in Figure 5.10.

Since the presence of the zener barrier introduces a further series resistance in the circuit, the relay actually needs to take account of the volt drop which will occur across the zener barrier. It can be shown that the maximum power available for the relay coil will exist

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* Apart from fault conditions. Such faults fall within the 'assume they will happen' category. (Non-countable faults.)

in a condition where the relay coil resistance is equal to the total 'end-to-end' resistance of the barrier. Allowing for the tolerance on the 300 Ω resistor and the cold resistance of the fuse, a 350 Ω relay coil would probably be the optimum value. However, a 400 Ω coil, which is a standard value, will be perfectly suitable. In approximate terms, half the voltage of the circuit will be dropped across the relay coil and half across the zener barrier, so the relay needs to have a 12 V 400 Ω coil although it is directly connected to a 24 V source.

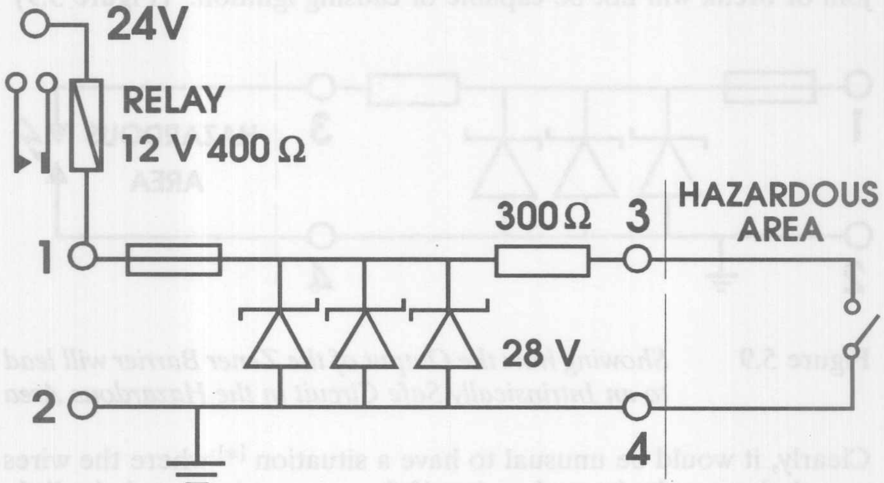

Figure 5.10 *Showing how a Relay may be Operated in the Non-hazardous Area, from a Switch which is part of an Intrinsically Safe Circuit in the Hazardous Area*

Now consider the situation shown in Figure 5.11. The non-hazardous area apparatus (which does not affect intrinsic safety conditions) is not shown, but instead of a switch in the hazardous area, the output from the barrier is now connected to a large capacitor.

If the wire at point 'A' were to break, then intrinsic safety is no longer purely a function of the output terminals of the zener

barrier, because the possibility of a capacitive discharge clearly needs to be considered.

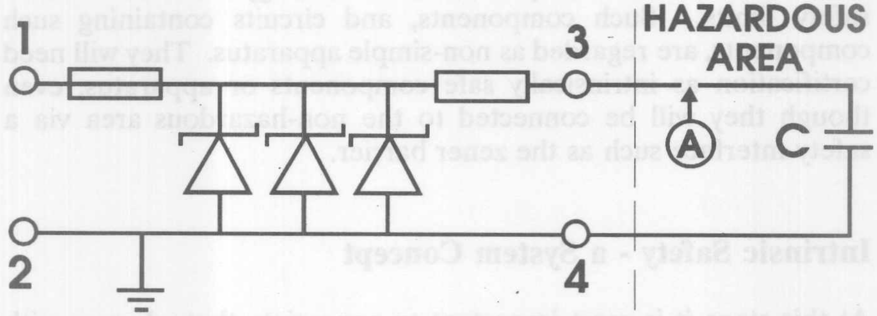

Figure 5.11 *Showing how the Intrinsic Safety Conditions are changed by the addition of a Capacitor in the Hazardous Area Circuit*

This leads to the conclusion that there is a difference in the assessment of intrinsically safe circuits dependent upon whether the apparatus in the intrinsically safe circuit [*] is non-energy storing (like the switch), or capable of energy storing (like the capacitor).

This distinction is extremely important in the protection technique of intrinsic safety. Apparatus which is non-energy storing can be added into an intrinsically safe circuit without any further certification conditions. Such apparatus is normally termed **simple apparatus**, and simple apparatus is fundamental to the use of intrinsic safety. Clearly, the switch shown in Figure 5.10 can be any switch at all. It may be a level switch, a 'break glass in event of fire' switch, a simple toggle switch, a micro-switch etc. The type of switch has no bearing on intrinsic safety considerations. Thus, within an intrinsically safe circuit, switches are regarded as simple

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* That is to say, the circuit connected to the output of the zener barrier.

apparatus and do not require certification.

On the other hand, the capacitor shown in Figure 5.11 needs to be assessed to see that the possible stored energy is within intrinsic safety limits. Such components, and circuits containing such components, are regarded as non-simple apparatus. They will need certification as intrinsically safe components or apparatus, even though they will be connected to the non-hazardous area via a safety interface such as the zener barrier.

Intrinsic Safety - a System Concept

At this stage it is most important to appreciate that whereas with other methods of protection (such as flameproof or increased safety) the safety of the item of apparatus can be assessed purely by consideration of that item alone, the intrinsic safety of an item of apparatus depends not only on the internal circuit, but also on what it is connected to externally. Thus intrinsic safety is a system concept, and every item within the circuit from the interface (associated apparatus) out into the hazardous area, will need to be considered *as a whole* before the circuit loop can be deemed intrinsically safe.

This aspect is crucial, because the system consideration often needs to be assessed by the installer rather than the designer of the intrinsically safe apparatus.

The first stage of system consideration is to examine the limitations and considerations for simple apparatus and non-simple apparatus. This is covered in detail in Chapters 7 and 8.

SUMMARY

- □ There are two categories of intrinsic safety, 'ia' and 'ib'
- □ The difference between 'ia' and 'ib' relates to the safety of the circuit under countable fault conditions. 'ia' is safer than 'ib'.
- □ Intrinsic safety 'ia' is suitable for all zones, 0, 1 and 2. 'ib' is acceptable for zone 1 and 2 but not zone 0.
- □ With a zener barrier interface, the maximum power which can be obtained in the hazardous area circuit will exist when the load resistance is equal to the output resistor of the barrier.
- □ Intrinsic safety design often makes use of **infallible** components (or assemblies of components). Infallible components have known failure modes and, since they will fail safe in the intended application they do not contribute to fault counts.
- □ The output of the barrier (and most types of associated apparatus) will be such that it is automatically safe for use with simple apparatus and will not be capable of giving a power dissipation in the intrinsically safe circuit of more than 1.3 watts.
- □ Intrinsic safety depends on the whole system rather than on individual items of apparatus. Intrinsic safety is a system concept.

NOTE:

Having now considered the internal circuit of the zener barrier in detail, unless the circuit has a bearing on the matter, from here on the zener barrier interface will be shown as a rectangular block. The user has no further need to appreciate the detail of its design and construction.

NOTES AND REFERENCES

1. For the reader who is not familiar with electronic components such as zener diodes, the zener diode may be regarded as a device which will allow current to pass in the direction of the arrow of the component symbol, but will prevent the passage of current in the opposite (zener) direction unless the component is subjected to a voltage exceeding its zener voltage. Thus the zener diode is a voltage limiting component, since the voltage across it cannot exceed the zener voltage. A variety of zener diodes are manufactured - the zener voltage being a parameter which is set at the component manufacture.

2. The maximum (short circuit) output current at the intended working voltage (a few volts less than the actual zener voltage) is normally limited by the output resistor to less than the fuse rating. Thus many zener barriers are regarded as short circuit proof, because the internal fuse cannot be open circuited by short circuiting the output.

3. At Edition 1 of EN 50 020, the requirement was to consider a prospective current of 4000 A. This tended to prevent the use of many microfuses. The reduction to 1500 A in the second edition means that suitable microfuses conforming to IEC 127 may be used.

4. Other current limiting devices such as series semiconductor current limiting devices are sometimes used in intrinsic safety design, but not for zener barriers, which have very prescriptive design conditions. The use of other current limiting techniques will be examined in later chapters.

5. The safety fuse considered here is a non-replaceable fuse within the zener barrier assembly. Many interface units now incorporate a replaceable fuse *in addition to the non-replaceable fuse*. The replaceable fuse is normally of a lower fusing rating than the non-replaceable fuse, or alternatively of

a 'quick-blow' variety in order to protect the non-replaceable fuse and thus save destroying the barrier.

If interface units do not have replaceable fuses, it is a good idea to add one externally, particularly for commissioning activity where large numbers of barriers are often destroyed by inadvertent polarity reversal etc.

6. It is, in fact, possible to design an 'ia' zener barrier with just two zener diodes if each zener diode is subjected to additional stringent tests, including pulse tests and elevated temperature tests. Whereas this approach was quite common at one stage, it is now less popular, and thus, rather than introduce a possible confusion, the two-diode-'ia'-barrier will not be examined. Those readers who wish to study such circuits should consult the standard EN 50 020 which specifies clearly the exact requirements.

   Whether the zener barrier is a two diode or three diode unit will not have any effect on how the unit is subsequently used, and the user will not normally know what internal design has been employed.

7. Other, 'softer' encapsulating materials may be used if the whole assembly is located within an outer enclosure such that the encapsulant is not forming part of the overall enclosure.

CHAPTER 6

Temperature Considerations

This chapter includes information on
Ignition from hot surfaces Temperature classification of small components Temperature classification of low wattage dissipation components

Temperature Considerations

Ignition Temperature and Hot Surfaces

In Chapter 1 it was explained that electrical apparatus which is to be located in the hazardous area needs to be protected against causing ignition of the hazard and it was seen that such ignition can be initiated either by arcs and sparks, or by hot surfaces. The principle of temperature classification was introduced and the six temperature classes were shown in Table 1.5.

In the discussion and explanation of Chapter 5, the only consideration was of ignition by arcs and sparks.

Consider the circuit shown in Figure 6.1. Providing the resistor is deemed to be purely resistive and does not also constitute an inductive element, then the circuit will be intrinsically safe, because, as shown in Chapter 5, a break or short anywhere will not be ignition capable.

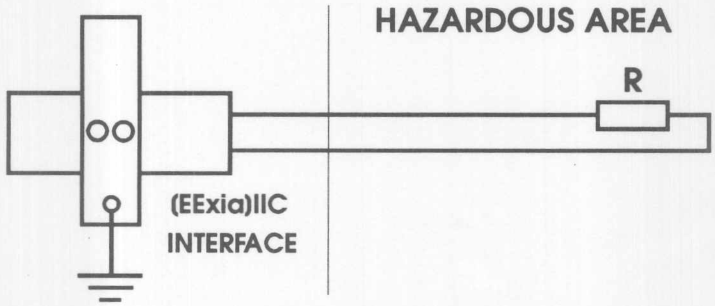

Figure 6.1 *Intrinsically Safe Circuit containing a Resistor which is Simple Apparatus*

However, clearly the resistor can dissipate some heat. Not much to be sure - in fact, it was shown that if the interface has safety

parameters of 28 V, 300 Ω, then it was not possible to dissipate more than 0.65 W in the hazardous area circuit under optimum, matched power, conditions.

But what about the physical size of the resistor? Clearly, if the resistor is infinitely large, and the electrical resistance is evenly distributed throughout the component, then the heating effect will, indeed, be negligible. But suppose the resistor is infinitely small. Surely then even the small wattage dissipation may create a hot surface?

In order to understand the position more clearly, and to establish an easy way of dealing with this possible problem, the actual mechanism by which ignition takes place needs to be considered in more detail. From the viewpoint of causing a hazardous area to catch fire or blow-up, the concern is that *ignition, once started, will self-propagate throughout the flammable atmosphere.* [*] Suppose, however, that the initial ignition was so small that, although there was some minute burning of the hazard local to the source, that burning did not itself have sufficient power to start the chain reaction which would propagate throughout the flammable mixture. [**] This is what happens with very small components - although there may be a hot surface, if the surface area is very small, even though the flammable atmosphere directly in contact may 'burn', ignition will not spread through the mixture.

As a result of research work it has been shown that, providing the surface area is less than 20 mm^2, then, even if the surface actually reaches as high as 275°C, it will not ignite flammable mixtures whose ignition temperature is above 135°C. Thus, for components which meet this size restriction, and do not present a hot surface exceeding 275°C, a temperature class of T4 may be awarded.

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* That is actually the definition of an explosion.

** This is a somewhat simplified explanation, but it encapsulates the concept and should suffice for the purposes of this book.

It has also been shown that if the surface area is at least 20 mm^2 in area, then if the component will not dissipate more than 1.3 W, a temperature class of T4 may be awarded without further assessment.[1]

Furthermore, if the surface area is at least 20 mm^2, but less than 10 cm^2 then T4 may be awarded providing the surface temperature does not exceed 200°C.

These three additional considerations are applicable to all small components used in intrinsically safe circuits; whether or not they are simple apparatus. However, as will be seen in the next chapter, it is particularly important for simple apparatus since many of the components which fall within the requirements for non-energy storing apparatus will meet either the size or wattage restriction and thus may be awarded a T4 rating.

The small components temperature allowances to achieve T4 are also applicable to group I apparatus. [2] The following table summarises the position.

Assessment for T4 Classification of Small and Low Power Components	
Total surface area excluding lead wires	**Requirement for T4 and Group I classification**
< 20 mm^2	Surface temperature ≤ 275°C
≥ 20 mm^2	Power dissipation ≤ 1.3 W (See Note)
≥ 20 mm^2 < 10 cm^2	Surface temperature ≤ 200°C
Note: The value of 1.3 W is reduced to 1.2 W if a 60°C ambient is required, and to 1.0 W if an ambient temperature of 80°C is required.	

Table 6.1 *Exceptions to Normal Requirements for T4 Classification*

Aside from the special allowances for small components described above, surface temperature needs to be assessed during certification.

It should be remembered that intrinsic safety does not involve either gas tight or flameproof enclosures, so temperatures both inside apparatus enclosures and the enclosure temperature itself will need to be considered.

The maximum surface temperatures assessed will be used to define the temperature classification of the apparatus. Table 1.5 in Chapter 1 shows the limits for each temperature class.

Ambient Temperatures Above 40°C

Normally, temperature classes are related to a maximum ambient temperature of 40°C and this limit is acceptable for the majority of applications. However, there are situations where apparatus may be required to operate at ambient temperatures above this level.

Clearly, if the temperature rise of some apparatus is say 80°C, then used in ambients where the temperature will not exceed 40°C, the total surface temperature will not exceed 80 + 40 = 120°C. This is too high for either T6 or T5, and a T4 rating would apply. However, if the ambient temperature was higher than 40°C; say 60°C, then the maximum surface temperature is likely to be 80 + 60 = 140°C. [3] This exceeds the maximum temperature for T4. (135°C)

When applying for certification, manufacturers may specify that they wish the apparatus to be tested and assessed for higher than normal ambient temperatures. In the case described, the apparatus could be awarded a temperature class of T3 in a 60°C ambient. This would be indicated by the marking **T3 Tamb 60°C** or **T3 Ta 60°C**.

Ambient Temperatures Below -20°C

Although it does not normally affect component choice and rating, it should be noted that (similar to the normal maximum ambient temperature of 40°C) there is a normal minimum ambient temperature applicable to certified apparatus. This is -20°C. If the apparatus is required to operate at temperatures below -20°C then this needs to be advised to the nominated body at the time certification is obtained.

The restrictive effect of low temperatures tends to be more pronounced on methods of protection other than intrinsic safety, for example, impact tests can have a more damaging effect at reduced temperatures. However, low temperatures can affect the electrical properties of some components, and there may be mechanical aspects even for intrinsic safety, especially if parts of the circuit are encapsulated.

Dual Marking

It is also possible to dual mark apparatus with varying temperature classifications for different maximum ambient temperatures. In the example described above, the apparatus would qualify for T4 in a normal ambient as well as T3 in ambients higher than 40°C. The label might state **T4, T3 Tamb 60°C**. Sometimes 'Ta' may be used in place of 'Tamb'.

Temperature Classification of Printed Circuit Tracks etc.

There are special requirements for assessing temperature of printed circuit board tracks, internal wiring etc. These will be considered in more detail in Chapter 13.

SUMMARY

- Ignition from hot surfaces needs to be considered for all apparatus.
- There are special relaxations on the normal temperature classification limits for small components and components with small power dissipation.
- Apparatus is normally limited to a maximum ambient temperature of 40°C unless the label states a higher ambient temperature.
- Apparatus is normally limited to a minimum ambient temperature of -20°C unless the label states a lower ambient temperature.
- Because of the 1.3 watts rule, T4 is normally attainable by default on intrinsically safe apparatus connected to the output of associated apparatus such as zener barriers.

NOTES AND REFERENCES

1. The fault conditions applicable to the category of intrinsic safety under consideration - 1 fault for 'ib' and 2 faults for 'ia' - are also applicable to temperature classification. Thus the wattage will be the wattage which can be dissipated under fault conditions.

2. Group I apparatus does not normally include a temperature classification.

3. It does not always follow that a direct rise in ambient temperature will correspond to a similar direct rise in surface temperature. Some components such as batteries do not have a linear temperature characteristic and may dissipate more wattage at higher temperatures.

CHAPTER 7

Simple Apparatus in Intrinsically Safe Circuits

This chapter includes information on
Simple apparatus definitions Use of simple apparatus Requirements for marking and certification of simple apparatus Simple apparatus located in the non-hazardous area

In Chapter 5, the role of the interface - associated apparatus - was explained, and the simplest form of interface - the zener barrier - was examined.

At the end of the chapter it was shown that while the interface ensured that a circuit containing only non-energy storing components, connected to its output, would be intrinsically safe, the same would not be true for a circuit which contained storage components such as capacitors or inductors.

The distinction between non-energy storing and energy storing components was explained, and the term **simple apparatus** for non-energy storing circuits was introduced. This chapter explains simple apparatus in more detail. (Chapter 8 looks at non-simple apparatus.)

The idea of simple apparatus has always existed with intrinsic safety, but the way in which simple apparatus has been defined and specified has changed as the various standards for intrinsic safety have evolved and as the technology has advanced.

Simple apparatus is intended to cover non-energy storing components and assemblies of components, which, providing they are part of an intrinsically safe circuit [*] may be added to the circuit **without the simple apparatus itself needing any certification or further consideration**.

Some examples of simple apparatus are:

- switches

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* This normally means that they are in a circuit which has a suitable interface of associated apparatus.

- □ thermocouples
- □ junction boxes
- □ resistors

Whilst the concept is easy to understand, it will be appreciated that, even considering the short list above, there are likely to be some 'grey areas' where it is not totally clear whether or not the component in question really is non-energy storing.

For example, what about a wire wound resistor? Is it purely resistive, or does it exhibit inductive properties as well?

Until the publication of the first edition of EN 50 014, simple apparatus was defined somewhat loosely by giving examples of simple apparatus. [*] For example, some of the earlier zener barrier certificates stated that 'the zener barrier should be located in the non-hazardous area, and may be connected to simple apparatus such as switches, thermocouples, light emitting diodes and resistive devices located in the hazardous area'.

At this stage, there was no international or European definition of simple apparatus, and different countries tended to treat the topic in differing ways; although always with the same end objective - of permitting the use of uncertified non-energy storing apparatus to be used in an intrinsically safe circuit without the need for further certification.

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* There is much to be said for not specifying things too tightly because it leaves the way open for new ideas and development to take place within the specification. As soon as the specification is tightened up, it is inevitable that some things will be precluded which would, in fact, be perfectly satisfactory. However, tightening up specifications is often necessary because as technology becomes more complex, the grey areas become more critical, and people need guidance on what is, and is not, acceptable.

In the UK, the Code of practice - BS 5345: Part 4 'Installation and maintenance requirements for electrical apparatus with type of protection 'i'. Intrinsically safe electrical apparatus and systems.' - defines simple apparatus as follows.

> *Simple electrical apparatus and components (eg thermocouples, photocells, junction boxes) may be used in intrinsically safe systems without certification provided that they do not generate or store more than 1.2 V, 0.1 A, 20 μJ and 25 mW in the intrinsically safe system in normal or fault conditions of the system prescribed in the standards ...*

When the first editions of the CENELEC Standards were published, there was no equivalent definition for simple apparatus in the intrinsic safety standard (EN 50 020) but the general standard (EN 50 014) contained a clause which stated:

> *Devices in which, according to the manufacturer's specifications, none of the values 1.2 V, 0.1 A, 20 μJ and 25 mW is exceeded need not be certified or marked.*

This is not particularly clear, because its inclusion in the general standard, rather than the intrinsic safety standard, tended to give the impression that the concept applied to all methods of protection and not just to intrinsic safety. This is clearly not the case.

This matter has been clarified with the publication of the second editions of the CENELEC Standards. The above wording has been deleted from the general standard and simple apparatus is now defined [1] in the second edition of EN 50 020, the intrinsic safety standard as follows:

The following apparatus shall be considered to be simple apparatus:

a) ***passive components, eg switches, junction boxes, potentiometer and simple semiconductor devices.***

b) ***sources of stored energy with well defined parameters, eg capacitors or inductors, whose values shall be considered when determining the overall safety of the system.***

c) ***sources of generated energy, eg thermocouples and photocells, which do not generate more than 1.5 V, 100 mA and 25 mW. Any inductance or capacitance present in these sources of energy shall be considered as in b).***

Simple apparatus shall conform to all relevant requirements of this standard but need not be certified and need not comply with clause 12. *[Marking requirements]* ***In particular the following aspects shall always be considered:***

1 ***Simple apparatus shall not achieve safety by the inclusion of voltage and/or current limiting devices.***

2 ***Simple apparatus shall not contain any means of increasing the available voltage or current, eg circuits for the generation of ancillary power supplies.***

3 ***Where it is necessary that the simple apparatus maintains the integrity of isolation from 'earth' of the intrinsically safe circuit, it shall be capable of withstanding the test voltage to earth in accordance with 6.4.12.*** *[Electric strength tests]* ***Its terminals shall conform to 6.3.1.*** *[Terminals]*

4 ***Non-metallic enclosures and enclosures containing light metals when located in the hazardous area shall conform to 7.3*** *[Electrostatic charges of enclosures or parts of enclosures of plastics material]* ***and 8.1*** *[Enclosures containing light metals]* ***of EN 50 014.***

5 ***When simple apparatus is located in the hazardous area it shall be temperature classified. When used in an intrinsically safe circuit within their normal rating switches, plugs and sockets and terminals are allocated a T6 temperature classification for group***

II applications and considered as having a maximum surface temperature of 85°C for group I applications. Other types of simple apparatus shall be temperature classified in accordance with clauses 4 [Grouping and classification of intrinsically safe apparatus and associated apparatus] and 6 [Apparatus requirements] of this standard.

Where simple apparatus forms part of an apparatus containing other electrical circuits the whole shall be certified.

This is clearly a much more comprehensive definition than previously, and some detailed examination is required.

Simple Apparatus - Full Explanation and Implications

First of all it should be understood that the part of the definition under a) and c) really covers all the apparatus which has previously been considered as simple apparatus. It is worth noting, however, that the previous voltage limit of 1.2 volts has been raised to 1.5 volts. This will result in some components which had previously been excluded from conforming to simple apparatus requirements to now fall within its definition. The ramifications of this will be considered later in the book.

Part b) of the definition positively addresses the question of 'how much, if any, stored energy is allowed in simple apparatus?' What this means is that *within the definition of simple apparatus some energy storage is permissible, providing it conforms to the capacitance or inductance permitted for intrinsic safety at the voltage or current levels which apply.* Previously, the only mention of energy storage was the 20 μJ value. This was, in practice, often very difficult to use when deciding whether or not a component with some capacitance or inductance was, indeed, simple apparatus. The 20 μJ figure has been removed and replaced with the more straightforward

requirement to assess the item under consideration to the normal capacitive or inductive curves.

It is, perhaps, that part of the definition which comes after the sub-clauses a, b and c, which has the most impact.

Firstly, it is clear that, with the exception of certification and marking, simple apparatus must meet all the requirements of the standard. A number of aspects are specifically cited.

- □ The requirement that simple apparatus shall not achieve safety by the inclusion of voltage and/or current limiting devices means that, for example, a piezoelectric device cannot be regarded as simple apparatus by the addition of a clamping zener diode (Figure 7.1)

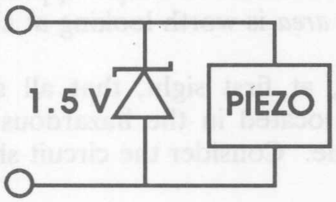

Figure 7.1 *A Piezoelectric Device protected against Voltages in excess of 1.5 V does not conform to Simple Apparatus requirements*

- □ The requirement that simple apparatus shall not contain any means of increasing the available voltage or current is aimed at preventing integrated circuits and other relatively complex semiconductor devices which may have elements *within the circuit* that can increase voltage or current, from falling within the simple apparatus net.

- The requirement that, if applicable, insulation from earth must be maintained by simple apparatus is not new. This requirement has always existed, but, because it was not previously clearly stated as part of the simple apparatus definition, it was often overlooked. The requirements for earthing are outside the direct scope of this chapter and will be looked at in more detail in Chapter 10.

- The requirement concerning plastics and light metal enclosures is aimed at drawing attention to the dangers of static risks and frictional sparking respectively. Again, these requirements have always existed, but have often been ignored where simple apparatus is concerned.

- The requirement concerning temperature classification of simple apparatus has, in general, already been explained. However, the reference to simple apparatus *which is located in the hazardous area* is worth looking at closer.

  It may seem, at first sight, that all simple apparatus will inevitably be located in the hazardous area, but this is not necessarily true. Consider the circuit shown in Figure 7.2.

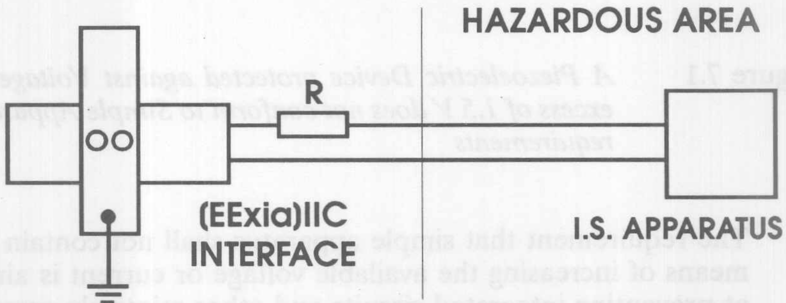

Figure 7.2 *Showing a Resistor - Simple Apparatus - located in the Non-Hazardous Area*

The resistor is clearly part of the intrinsically safe circuit, and is located on the hazardous area side of the interface. However, its function is to assist in some calibration activity, and the resistor is physically located in the non-hazardous area - probably in the interface cabinet in the control room. [*] Clearly, since the simple apparatus is located in a non-hazardous area, it does not matter if it gets hot; there is no hazard to ignite.

Practical Aspects of Simple Apparatus

Now that the concept of simple apparatus has been explained, it is worth considering some typical circuits to see how the simple apparatus rules assist the user and installer of intrinsically safe apparatus.

Consider the circuit shown in Figure 7.3. It shows an interface unit (associated apparatus) connected to various items of apparatus in the hazardous area. All the items in the hazardous area are simple apparatus, so the only certified apparatus in the whole circuit is the interface.

The associated apparatus is the 28 V 300 Ω zener barrier considered previously. Thus the wattage of any item in the hazardous area circuit cannot exceed 0.65 W, and since, with the exception of the junction box, everything has a surface area of less

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* It would perhaps be more normal to locate such a resistor on the non-hazardous area side of the interface, but there are circumstances where it needs to be on the hazardous area side. It is worth noting that the arrangement shown does have some implications for testing and calibration, since any portable test equipment attached to the resistor, for example to measure the voltage across it, could affect the intrinsically safe circuit, and will thus need to be an intrinsically safe instrument. Such considerations are dealt with more fully elsewhere in the book.

than 20 mm^2, T4 will be applicable. The junction box is covered by those parts of the simple apparatus definition dealing with terminals, and thus is deemed to be T6. All the apparatus and circuitry will withstand an insulation test to earth of 500 V rms ac, so there are no problems in meeting the earth insulation requirements.

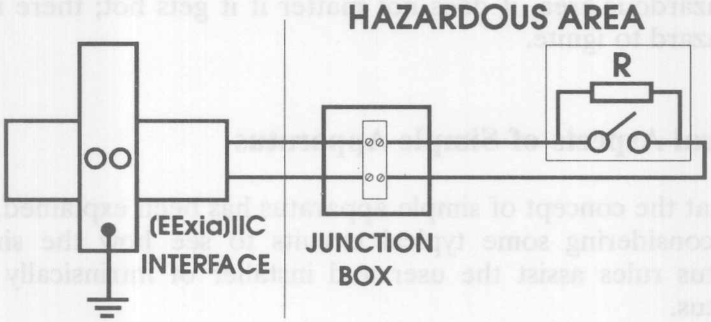

Figure 7.3 *Intrinsically Safe Circuit comprising Associated Apparatus and Simple Apparatus*

Conversely, consider the circuit shown in Figure 7.4.

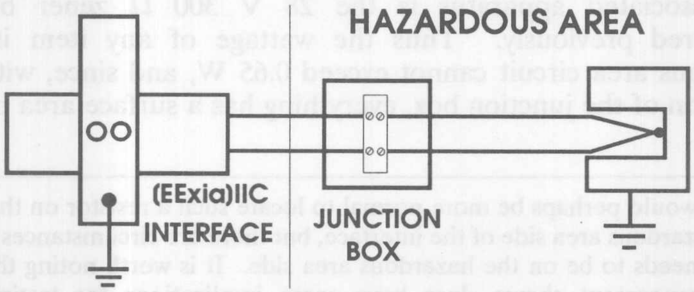

Figure 7.4 *An Intrinsically Safe Circuit containing Simple Apparatus - or is it?*

At first sight, the thermocouple appears to meet the requirements of simple apparatus. It may generate some slight voltage, but clearly significantly less than 1.5 volts. It certainly will not be able to provide 100 mA. But the thermocouple has been both mechanically **and electrically** connected to the metal which it is measuring, and this in turn is at earth potential.

This is where the earthing requirement stated in the simple apparatus rules comes into force. This requirement [2] states that..

The insulation between an intrinsically safe circuit and the frame of the electrical apparatus or parts which may be earthed shall normally be capable of withstanding an rms ac test voltage of twice the voltage of the intrinsically safe circuit or 500 V, whichever is greater.

Clearly, the thermocouple will not withstand a 500 V test to earth; it is connected to earth. Thus the rules for simple apparatus do not apply and some other solution (possibly still within the requirements of intrinsic safety, but outside the freedom of uncertified simple apparatus) must be found. [*]

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* It is always best, if at all possible, to use thermocouples which are electrically insulated from their surroundings. Normally the metal sheath of the thermocouple is insulated from the circuit and most conventional thermocouples will easily withstand a 500 V insulation test.

SUMMARY

- □ Simple apparatus allows non-energy storing components and assemblies of components to be used without certification.
- □ Simple apparatus must still meet requirements for insulation from earth.
- □ Simple apparatus may be located in the non-hazardous area as well as the hazardous area.
- □ Simple apparatus must be temperature classified unless the small components and low wattage rules apply.
- □ Switches, junction boxes and terminals will normally achieve T6.

NOTES AND REFERENCES

1. See EN 50 020, Edition 2, Clause 5.4.
2. EN 50 020, Edition 2, Clause 6.4.12, insulation requirements.

CHAPTER 8

Non-Simple Apparatus

This chapter includes information on
Energy storing apparatus such as solenoids, transmitters and energy generating apparatus such as piezoelectric devices Marking information for effective capacitance and inductance Use of capacitive and inductive ignition curves Intrinsic safety system consideration

Non-Simple Apparatus

In Chapter 7 the concept of simple apparatus was explained and it was seen that, since non-energy storing or generating components would have no effect on the intrinsic safety of the circuit, they could be used without any certification ramifications.

At the end of that chapter it was shown that if the apparatus could generate or store electrical energy, then clearly this would affect the intrinsic safety considerations. Such apparatus will not be simple apparatus.

This chapter looks at apparatus, which is not simple apparatus and examines the ways in which it may still be intrinsically safe. (For those readers wanting more detailed information on the design of intrinsically safe apparatus, consult Chapter 13.)

Before proceeding, it is worth considering some of the typical sorts of apparatus and components which will not be simple apparatus.

The following list is by no means comprehensive, but will serve to indicate the types of component and circuit which will need full assessment and certification before they can be used in an intrinsically safe circuit.

Solenoid Coils

These will exhibit inductance which will almost certainly be greater than the maximum permitted under the inductive ignition curves. The inductive energy will need to be suppressed in some way.

Apparatus Containing Integrated Circuits

Such circuits commonly contain internal capacitance and may also have voltage or current increasing arrangements.

4-20 mA Transmitters

Almost always include circuits which contain capacitors.

Transducers containing Piezoelectric Devices

The piezoelectric device can generate high voltages.

Apparatus containing Batteries

Clearly the voltage of the battery will influence the voltage present in the intrinsically safe circuit.

Consideration of Energy Storing Circuits

Although so far only the ignition curves for resistive circuits have been considered, there are also ignition curves for inductive and capacitive circuits. (See Appendix 1) Clearly, as will be seen, if the levels of capacitive or inductive energy are small then intrinsic safety may still be achieved directly.

When viewing the curves, remember that the factor of safety of 1.5 still needs to be included.

With capacitive considerations, the factor of safety is applied to the voltage. Thus, looking at the capacitive curves, it will be seen that if the actual maximum voltage on the circuit is say 30 volts, applying a factor of safety of 1.5 and entering the curves at 45 volts gives a maximum safe level of capacitance of 0.06 μF. [1] If the capacitance is greater than this value, then it will need to be protected in some way. This is normally achieved by the inclusion of a series resistor which will have the effect of limiting any capacitive discharge. Unless the circuit is only intended for group I application, testing and assessment using spark test apparatus will

be necessary to determine if the combination of capacitor and resistor is safe. [2]

For inductive circuits, the factor of safety of 1.5 needs to be applied to the circuit current. If the level of inductance is too great for intrinsic safety, then the effect of the inductive energy can normally be negated by using diodes across the inductor to prevent any inductive discharge jeopardising the intrinsically safe circuit.

Piezoelectric devices are normally protected by shunting with zener diodes such that the resulting circuit will perform its intended function, but cannot produce excessive voltage.

Certification of Intrinsically Safe Apparatus

By now it will be clear that apparatus which contains electrical energy storing or generating parts needs careful assessment to check that it conforms to the requirements of intrinsic safety. This is, of course, the process of certification. Apart from components and simple circuits which can clearly be shown to be simple apparatus, certification is required for all intrinsically safe apparatus. [3]

Suppose that a transmitter has been designed to comply with the standard and has been certified. As part of the certification work the internal capacitance (and/or internal inductance) of the transmitter will either have been directly assessed from the curves, or tested using the break flash apparatus. The end user does not need to know how the assessment was carried out, but since the capacitance is not zero, he does need to know the overall capacitive (and inductive) effect of the transmitter within the overall intrinsically safe circuit loop.

As will be seen, the *effective capacitance* (and/or effective inductance) of the apparatus (in this case, the transmitter) will influence how the apparatus can be used. The certification process

will determine the overall effect of the circuit and, taking account of all the capacitors in the circuit (some of which may be protected with series resistors, while others probably are not) will state what the capacitive effect of the apparatus - at the connection terminals - will be. This is known as the **maximum internal capacitance** of the apparatus and is denoted by 'C_i'. This value will be included on the label of the certified apparatus. (In edition 1 of the CENELEC standard EN 50 020, the value of effective maximum internal capacitance was denoted 'C_{eq}'. For all practical purposes, C_i and C_{eq} have identical meanings.)

Similarly, the **maximum internal inductance** - 'L_i' - will be marked. (In edition 1 of the CENELEC standard EN 50 020, the value of effective maximum internal inductance was denoted 'L_{eq}'. For all practical purposes, L_i and L_{eq} have identical meanings.)

Note that, if the apparatus is not simple apparatus and thus is a certified item of intrinsically safe apparatus, there will now be (at least) two certificates [4] - the certificate for the apparatus itself and the certificate for the associated apparatus which provides the safety interface with the non-hazardous area part of the circuit. (Figure 8.1).

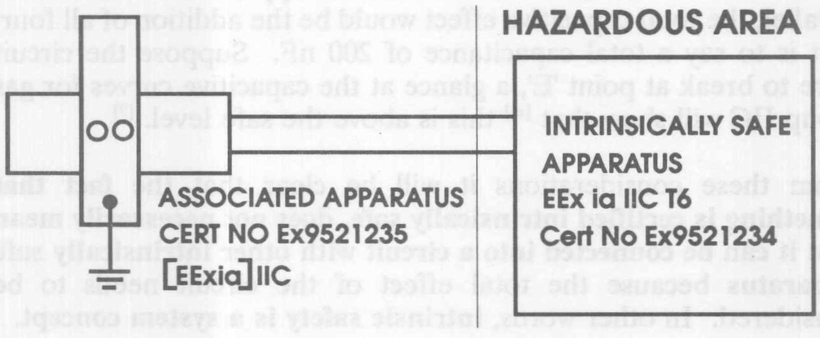

Figure 8.1 *Showing the Apparatus Certificates applicable to a Circuit involving Intrinsically Safe Apparatus which is not Simple Apparatus*

The label and certificate for the associated apparatus will contain information on the maximum capacitance and inductance which can be safely connected to its output terminals. This information will be denoted by 'C_o'[5] and 'L_o'.[6] These values, together with the maximum voltage and current output values of U_o (the maximum open circuit output voltage)[7] and I_o (the maximum current which can be taken from the output terminals)[8] enable the designer to select associated apparatus appropriate and safe for the intrinsically safe circuit loop.

Although the circuit loop now contains other than simple apparatus, simple apparatus may, of course, still be added to the circuit. So junction boxes, terminals, etc. may still be included without further certification.

Consider now what would happen if, for some reason, several items of certified intrinsically safe apparatus were to be connected together in one circuit, as shown in Figure 8.2.

The position, as far as intrinsic safety is concerned is now more complex. The maximum internal capacitance of apparatus 'A' may be added to the maximum internal capacitance of apparatus 'B' and so on. In this case, with four items of apparatus connected in parallel, the total capacitive effect would be the addition of all four, that is to say a total capacitance of 200 nF. Suppose the circuit were to break at point 'E', a glance at the capacitive curves for gas group IIC will show that [*] this is above the safe level.[9]

From these considerations it will be clear that **the fact that something is certified intrinsically safe, does not necessarily mean that it can be connected into a circuit with other intrinsically safe apparatus** because the total effect of the circuit needs to be considered. In other words, **intrinsic safety is a system concept.**

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* Remember to apply the factor of safety to voltage. The level to check is thus 28 x 1.5 = 42 V. At this voltage, the maximum permitted capacitance for gas group IIC is 83 nF.

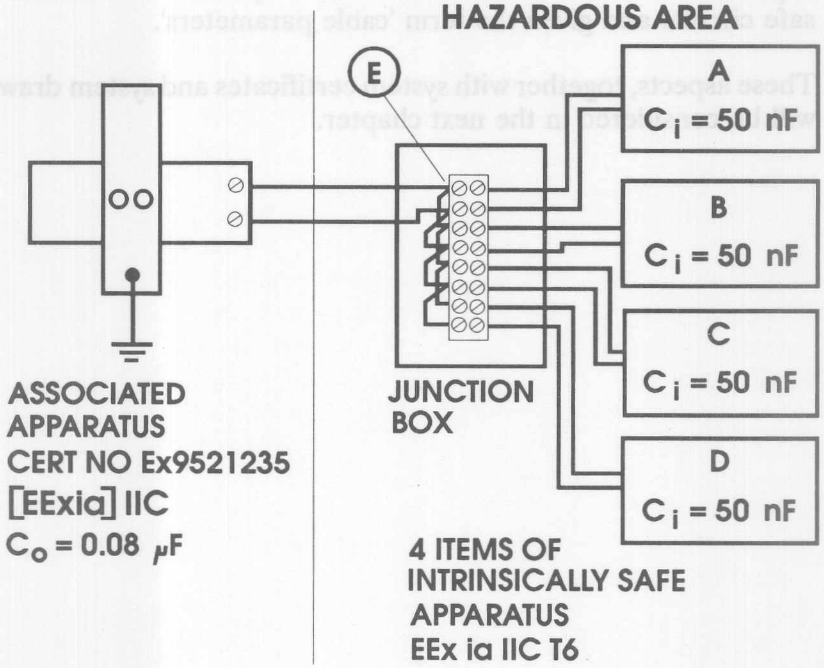

Figure 8.2 *Several items of certified apparatus connected together. Is the resulting combination intrinsically safe?*

Intrinsic safety cannot be assessed by considering individual items of apparatus. The effect of the entire circuit from associated apparatus onwards needs to be considered to ascertain if the whole circuit loop will be intrinsically safe.

So far, only the effect of stored energy in the items of intrinsically safe apparatus has been considered but it will be appreciated that the interconnecting cables will also act as a source of stored energy,

since they will exhibit some capacitance and inductance. The capacitance and inductance of cables is specified for intrinsically safe circuits and given the term 'cable parameters'.

These aspects, together with system certificates and system drawings will be considered in the next chapter.

SUMMARY

- □ Apparatus which is non-simple apparatus needs to be certified.
- □ Certified intrinsically safe apparatus will include details of the maximum internal capacitance C_i (or C_{eq}) and maximum internal inductance L_i (or L_{eq}) on the label.
- □ The fact that something is certified does not necessarily mean it is safe or suitable for use in a particular intrinsically safe circuit, or in combination with other items of intrinsically safe apparatus, or with any particular item of associated apparatus.
- □ Intrinsic safety is a system concept.
- □ The values of the output parameters of the associated apparatus need to be carefully checked with the input parameters of the intrinsically safe apparatus to ensure that the total circuit loop is intrinsically safe.

NOTES AND REFERENCES

1. The second edition of EN 50 020 gives tables as well as the actual curves of permitted values for group II. Because the curves are a little difficult to interpolate between gradations on the axes, designers will normally find the tables preferable when doing detailed assessment and design work.

2. Previous standards, and edition 1 of the CENELEC Standard EN 50 020, included curves showing the effect of a capacitor in series with a resistor. These curves have been removed from the second edition of EN 50 020, *except for gas group I.*

   It should be noted that it was never possible to use the curves showing capacitance and resistance for assessing combinations of capacitors, some of which were unprotected and some of which were resistance protected. Such combinations always needed testing using the break flash apparatus. This fact was not always appreciated, and sometimes the curves for resistance protected capacitance were incorrectly used. This is why they have now been removed from the standard at its second edition.

3. Certification within the EC will normally be carried out by a nominated body and will result in a Certificate of Conformity for the apparatus concerned. This will mean that, in addition to being coded EEx.., the apparatus can exhibit the Distinctive Community Mark. (See Chapter 3.)

4. As will be seen in the next chapter, there may also be a system certificate, showing that the combination has been assessed, and stating any requirements for the installation and use of the resulting circuit loop.

5. C_o was denoted C_{ext} on associated apparatus certified to edition 1 of EN 50 020.

6. L_o was referred to as L_{ext} on associated apparatus certified to edition 1 of EN 50 020.

7. U_o was referred to as U_z or $U_{max\ out}$ on associated apparatus certified to edition 1 of EN 50 020.

8. I_o was normally referred to as $I_{max\ out}$ on associated apparatus certified to edition 1 of EN 50 020.

9. Apparatus and associated apparatus certified to edition 1 of En 50 020 should be treated as follows:

   a) Associated apparatus: U_z $I_{max\ out}$

      The values of maximum load capacitance and inductance should be noted in the certificate if they are not indicated on the label. Alternatively, use the value of U_z x 1.5 to determine the maximum capacitance which can be conncted to the output.

   b) Certified apparatus:

      The certified intrinsically safe apparatus will have a value for C_{eq}. The addition of the values of C_{eq} for all the intrinsically safe apparatus in the circuit loop (system) must be less than the value obtained for a) above.

Alternatively, if there is a system certificate for the desired apparatus combination, these parameters will have already been checked.

CHAPTER 9

Intrinsic Safety System Considerations

This chapter includes information on

- System drawings
- System certificates
- Cable parameters: C, L, L_o/R_o (L/R)
- C_i, C_o, I_i, I_o, L_i, L_o, U_i, U_o
- System safety of simple and non-simple apparatus
- Basic selection of associated apparatus with certified apparatus

Intrinsic Safety System Considerations

In the last two chapters the different ways in which intrinsically safe apparatus is treated, depending on whether the simple apparatus rules apply, has been explained, and it has been shown that intrinsic safety depends on the parameters of the whole circuit loop and not just on individual items within the loop.

In this chapter the overall system is discussed in more detail, with the role of system certificates and system drawings explained in detail.

The reader should note that much of the previous information has been by way of general explanation of the method of protection intrinsic safety. Whilst that information assists the user and installer to understand the technique, much of it does not affect such people on a day-to-day basis. The systems aspect, on the other hand, is crucial to those people who are involved with loop design and installation.

The Parts of an Intrinsically Safe System

Consider the intrinsically safe circuit loop shown in the block diagram in Figure 9.1

The certified items comprise the interface, located correctly in the non-hazardous area, and a 4-20 mA transmitter. The junction box is simple apparatus and does not require certification.

The first stage is to check that the transmitter is safety compatible with the interface.

When the transmitter was assessed (during its certification) for capacitance and inductance, it was necessary to define the voltage and current which could be safely applied to the transmitter terminals.

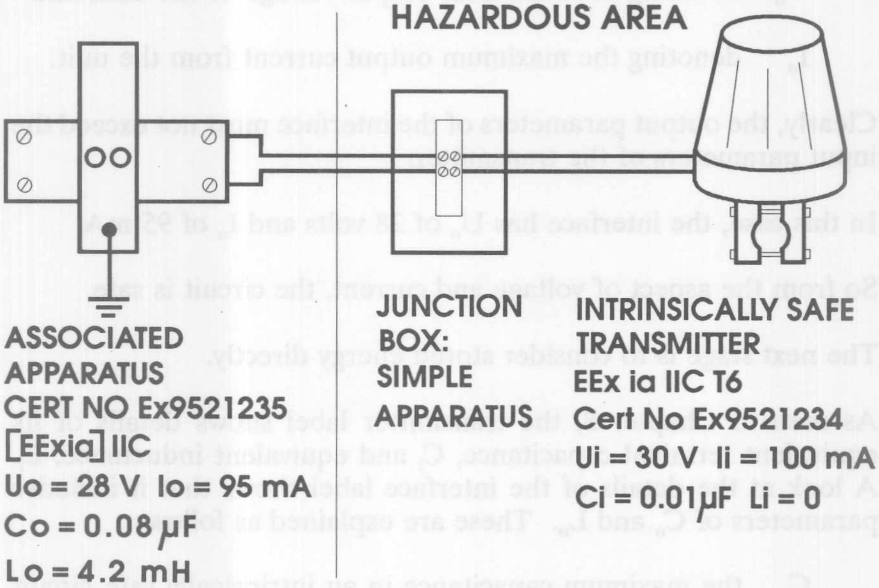

Figure 9.1 *The parts of an Intrinsically Safe System*

It was shown in Chapter 8 that data on the maximum input voltage and maximum input current to certified apparatus is specified and that this information is included on the apparatus label by:

U_i denoting the maximum voltage which may be applied to the terminals, and

I_i denoting the maximum current which can be applied to the terminals.

In the example shown, the transmitter has $U_i = 30$ V and $I_i = 100$ mA.

Looking now at the interface, it was explained in Chapter 5 that the maximum *output* levels of the interface were indicated by:

U_o denoting the maximum output voltage of the unit, and

I_o denoting the maximum output current from the unit.

Clearly, the output parameters of the interface must not exceed the input parameters of the transmitter.

In this case, the interface has U_o of 28 volts and I_o of 95 mA.

So from the aspect of voltage and current, the circuit is safe.

The next stage is to consider stored energy directly.

As seen in Chapter 8, the transmitter label shows details of its equivalent terminal capacitance, C_i and equivalent inductance, L_i. A look at the details of the interface label shows that it includes parameters of C_o and L_o. These are explained as follows:

C_o the maximum capacitance in an intrinsically safe circuit that can be connected to the terminals without invalidating intrinsic safety.

L_o the maximum inductance in an intrinsically safe circuit that can be connected to the terminals without invalidating intrinsic safety.

In this case, $C_o = 0.08\ \mu F$ (80 nF) and $L_o = 4.2$ mH.

This time, the values on the interface need to be *greater* than the values on the transmitter. They are, so this aspect too appears to be acceptable. [*]

If a further item of certified apparatus was to be added to the

* The possibility of stored energy in the interconnecting cables has not yet been considered, hence the slight reservation in the statement.

circuit, then it would also need to be suitable from the viewpoint of its U_i and I_i, and **the total equivalent capacitance of both the transmitter and the additional item, and the total inductance of both the transmitter and the additional item would need to be *less* than the permitted external capacitance and inductance of the interface.**

Expressed mathematically, for an intrinsically safe circuit comprising 'n' items of certified apparatus in the hazardous area, and an interface in the non-hazardous area:

$$C_{o\ \mathrm{INTERFACE}} \geq C_{i\,(1)} + C_{i\,(2)} + C_{i\,(3)} + \ldots C_{i\,(n)} + C_{\mathrm{CABLE}}$$

and similarly

$$L_{o\ \mathrm{INTERFACE}} \geq L_{i\,(1)} + L_{i\,(2)} + L_{i\,(3)} + \ldots L_{i\,(n)} + l_{\mathrm{CABLE}}$$

It is important to appreciate that the values of C_o and L_o are quoted on the interface label (and certificate) for the gas group for which the output is certified. Thus, if the interface is certified [EEx ia]IIC, then the parameters apply to group IIC applications. It would seem reasonable that the maximum safe levels of connected capacitance and inductance may be increased if the actual application is for IIB or IIA.

Previously (that is to say with certifications to the first edition of EN 50 020, and to national standards such as SFA 3012 [1]) the permitted levels of capacitance and inductance specified for gas group IIC could be multiplied by 3 for IIB applications, and by 8 for IIA applications.

Although it is not directly stated, it would appear that the correct procedure, following the second edition of EN 50 020, is to use the maximum output voltage and current parameters of the associated apparatus (U_o and I_o) and apply these (with the factor of safety of 1.5) to the table or curve of permitted capacitance and inductance contained in Appendix A2 of the standard. This will give maximum

permitted values for gas groups IIA and IIB which may then be regarded as C_o and L_o values for these gas groups.

The Effect of Additions of Simple Apparatus on the System

In the past, simple apparatus has been ignored when assessing stored and generated energy for the overall safety of an intrinsically safe circuit loop (system). However, the new definition of simple apparatus, given in the second edition of EN 50 020 allows *sources of stored energy with well defined parameters, eg capacitors or inductors...* to be included within the rules for simple apparatus. This change from earlier definitions of simple apparatus, although opening up a number of possibilities, has the effect of requiring that the .. *values shall be considered when determining the overall safety of the system.* [*]

In this case, the junction box certainly can be ignored as far as stored energy is concerned since it is simple apparatus which has no capacitive or inductive effect.

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* Whilst the reasoning is quite clear, in the author's opinion this change to the definition of simple apparatus and the resulting need to consider its effects when establishing system safety is unfortunate and unwelcome. In reality, few people will find it worthwhile to establish simple apparatus by defining levels of capacitance and inductance, and even fewer will want to be bothered with considering this when arranging a system.

(Clearly the manufacturer of the apparatus which is to be regarded as simple apparatus will not mark the capacitance or inductance on the apparatus, because, if it is simple apparatus, it is presumably some standard item, and in any case, marking of simple apparatus is not required. So it must be concluded that it is the user of the apparatus who has to define the capacitance and inductance of such items. All very laudable, but, extremely unlikely to happen! Furthermore, there is a real danger that if it starts to get complex, people will shy away from using intrinsic safety, which would be very counterproductive.)

However, what about the interconnecting cable? Surely the cable has capacitive and inductive properties?

Cable Parameters

Cables will of course provide some capacitance and inductance to the circuit. In reality, the amounts are small, and, unless the cable length is excessive [2] and the circuit is operating in gas group IIC, then cable parameters can normally be safely ignored.

However, if cable parameters do need to be established, then the permitted values may be ascertained as follows: [3]

Permitted maximum cable capacitance C_c

$$C_c = \quad C_o - (C_{i\,(1)} + C_{i\,(2)} + \dots C_{i\,(n)})$$

Permitted maximum cable inductance L_c

$$L_c = \quad L_o - (L_{i\,(1)} + L_{i\,(2)} + \dots L_{i\,(n)})$$

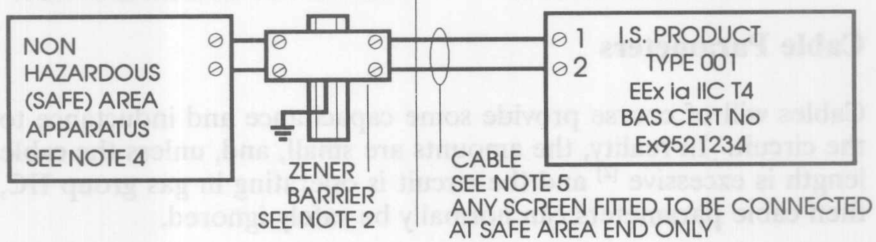
System Certificates and Drawings

The reader would, at this stage, be forgiven for thinking that the whole thing was becoming a little complex, particularly when compared to other methods of protection where all that is normally required is to select the apparatus and install it using suitably mechanically protected cable and the appropriate cable gland.

Because of this general view, it has long been held that the suppliers of intrinsically safe apparatus should give the end user sufficient information to enable him to install and use the apparatus with the minimum of further difficulty.

DRG A-1234

NON HAZARDOUS (SAFE) AREA | **HAZARDOUS AREA**



NOTES

1 The installation must conform to the National requirements in the country of use. For example UK installations must conform to BS 5345: Part 4: 1977.

2 Zener barrier type MTL 788. Certified [EEx ia] IIC. Certificate number Ex832452.

3 The electrical circuit in the hazardous area must withstand an AC test voltage of 500 V rms test to earth or frame of apparatus for one minute without breakdown.

4 Non-Hazardous (safe) Area Apparatus. Unspecified, except that it must not be supplied from nor contain under normal or abnormal conditions, a source of potential with respect to earth in excess of 250 V ac rms or 250 V dc.

5 Cable Parameters. The capacitance, and the inductance or the inductance to resistance ratio of the interconnecting cables shall not exceed the following parameters:

GAS GROUP	CAPACITANCE μF	INDUCTANCE mH	INDUCTANCE / RESISTANCE RATIO μH/Ω
IIC	0.01	0.37	24
IIB	0.36	1.11	72
IIA	1.01	2.96	192

THE I.S. PRODUCT COMPANY | DRAWING NUMBER A-1234

SYSTEM DRAWING FOR INTRINSICALLY SAFE I.S. PRODUCT SYSTEM

SYSTEM CERTIFICATE Ex9521235

ISSUE

DATE 7.1.95

DRAWN BY HEXAGON TECHNOLOGY LIMITED

Figure 9.2 *System Drawing applicable to Intrinsically Safe System Certificate*

This has led to the issue of system certificates for intrinsic safety. In other words, in addition to the certificates for the apparatus (normally known as certificates of conformity) there may also be a system certificate which clearly states which items of apparatus may be connected together to form a certified system or circuit loop.

Accompanying the system certificate will be a system drawing - normally a block diagram similar to that shown in Figure 9.2. Unlike certified drawings for the apparatus, the certified system drawing is not normally confidential to the manufacturer, and indeed is produced primarily to assist the installer and user.

As will be seen, the system drawing (and the system certificate) directly specifies the applicable cable parameters for all gas groups, and identifies each item of certified apparatus in the system.

Clearly, the presence of such a certificate or system drawing does not prevent the addition of simple apparatus into the circuit but, as has been stated, if the simple apparatus does exhibit capacitive or inductive elements, then these should be allowed for against the permitted cable parameters for the gas group of installation.

The reader may have noticed that, in addition to cable capacitance and inductance, a parameter known as the 'inductance to resistance ratio' (L/R or L_o/R_o) is specified. This is really an easy way of establishing the maximum effective cable inductance.

Since the inductive stored energy is proportional to the square of the current ($Q = LI^2$) the resistance of the cable will have some effect on the resulting stored energy. To take the two extremes, if a cable has zero length, it will clearly have zero inductance. On the other hand, if a cable has infinite length, it will have infinite resistance, in which case no current will flow, and thus again there will be no inductance. In fact, a plot of cable length against inductance, gives results as indicated in Figure 9.3

In other words, for any cable, there will be an optimum (worst case) length for the effects of inductive stored energy. If the cable is either shorter or longer than this optimum length, then the inductance will be less than the maximum. If the maximum inductance is equated to resistance, rather than length [*] then the worst case inductance to resistance can be specified.

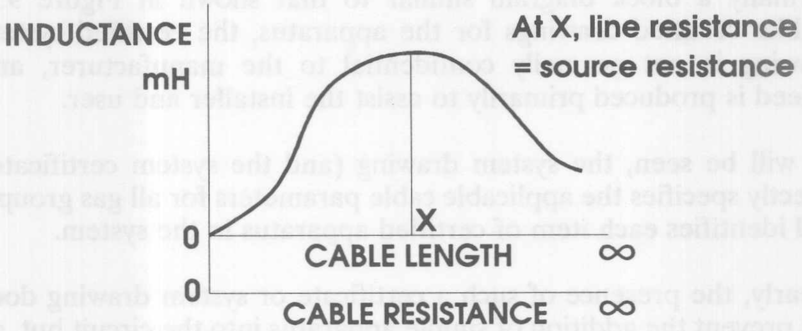


Figure 9.3 *Cable Inductance versus Cable Length and Resistance*

By specifying a maximum inductance to resistance ratio on the system documents, if the user wishes or needs to check cable inductance, he can simply take a short length of the proposed cable, measure its inductance, measure its resistance, and check that the L/R of the sample is less than the L/R specified for the system. Then, whatever length of cable is used, the maximum permitted inductance will not be exceeded.

Again, it should be emphasised that users should not allow apparent complexity of system considerations to detract from the inherent simplicity of intrinsic safety. Most manufacturers of intrinsically safe apparatus, and especially the manufacturers of

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* Since length to resistance of a cable is a linear relationship.

certified associated apparatus are only too willing to give excellent and accurate assistance to the installer or system designer which normally obviates the need for any calculations etc. to be done. Indeed, except in very rare circumstances, it is extremely doubtful if the installer, system designer (as opposed to apparatus designer) or user ever needs to refer to the CENELEC design standards such as EN 50 020.

System Standard

To allow for the fact that intrinsic safety is system dependent rather than apparatus dependent, intrinsic safety, unlike all the other methods of protection actually has a system standard which enables system certificates to be issued by the nominated body. The standard is EN 50 039. [4] [5]

Apart from enabling the issue of system certificates, providing certain information on the types of cable which may be used for intrinsically safe circuits (especially where multicore cables are used) and giving some information on system labels, which is discussed below, this standard contains very little information. (Cable information is examined in more detail in Chapter 12.)

System Labels

The systems standard referred to above, requires that intrinsically safe systems shall be marked in a 'strategic' position. Quite where the marking should be is not clear, as the standard states that "*The marking should normally appear on or adjacent to the principal item of electrical apparatus in the system or at the interface between intrinsically safe and non-intrinsically safe circuits*". Although this may appear clear enough, it is often not at all obvious which is the principal item of electrical apparatus.

In reality, very few users bother about the system label, and although most of the nominated bodies now require the information to be indicated on the system drawing, they do not expect to have any input as to how or where such information is attached.

The system information which is supposed to be marked includes the letters 'SYST' and the (system) certificate reference.

SUMMARY

- The safety of the method of protection intrinsic safety depends on the correct and compatible selection of all the items in the loop or system from the associated apparatus and throughout the hazardous area circuit.

- The compatibility must either be assessed by the system designer or installer, or conform to the specification on a system drawing and system certificate.

- If no system certificate is available, the values of U_o (U_z) I_o ($I_{max\ out}$) on associated apparatus and U_i and U_o etc, which are noted on apparatus labels provide the information to assess compatibility.

- The possibility of stored energy in interconnecting cables may need to be considered.

- Cable parameters (C, L and L/R or L_o/R_o) do not normally need to be considered for short cable runs or for gas group IIA and IIB installations.

NOTES AND REFERENCES

1. SFA 3012: BASEEFA standard on intrinsic safety.

2. It is rare for cable lengths of less than 1 km to present real capacitive or inductive problems.

3. The assumption is that the circuit is connected to one item of associated apparatus. If there are two or more items of associated apparatus, for example a circuit using two zener barriers, then the position is more complex and guidance should be sought from the manufacturer or system certificate.

4. EN 50 039: Electrical apparatus for potentially explosive atmospheres - Part 9, specification for intrinsically safe electrical systems.

   (This standard, at least for the time being, remains at its first edition, and has not be revised to edition 2.)

5. Before the CENELEC standards, national standards such as the BASEEFA standard SFA 3012 gave information to enable systems certificates to be issued.

CHAPTER 10

Earthing of Intrinsically Safe Circuits

This chapter includes information on
Earthing zener barriers Earthing of cable screens and armour Earth connection integrity Insulation of intrinsically safe circuits from earth Circuits which cannot be isolated from earth in the hazardous area Galvanic isolation of circuits

Earthing of Intrinsically Safe Circuits

The ultimate safety of many intrinsically safe systems depends on the integrity of a good earth system. This chapter considers the requirements for earthing and explains what the requirements mean and how they can be achieved.

At the outset, it should be clearly understood that there is no such thing as 'an intrinsically safe earth'. Earth, in electrical terms, is the base reference point of a supply whose neutral is connected to earth. For example, in the UK, with the normal 'mains' power supply arrangement of a three phase system, the neutral is electrically connected to earth and thus the supply or line voltage is a voltage with respect to earth.

It may also assist some readers to think in terms that, for all practical purposes, the earth (the world) has zero resistance. That is to say, it is pretty much a perfect conductor. If it was possible to measure the resistance from one side of the world to a point directly opposite it, the resistance would be very small. This is not to say that a small bit of earth will not have resistance, but the world (from one side to the other) is a conductor of large cross sectional area. Thus although a little bit of earth may have some considerable resistance, all the parallel paths available to earth as a mass provide a low resistance.[*]

Furthermore, of course, on many plants, there are metal clad buildings, buildings constructed on steel frameworks, metal pipes and cable trays. All of this has the effect of ensuring that the resistance between one point on the plant and another is very low.

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* Purists may feel cheated or upset by this explanation, but in the author's experience, there is a tendency for people not to believe that 'earth' really is a conductor at all, and this is often the reason why earth faults on intrinsically safe circuits are not understood or easily resolved.

Undoubtedly, there are exceptions. If a plant is built in several separate buildings, and the whole thing is standing on granite rock which is dry, then the resistance between one earth point and another will be quite high.

So overall, the earth is a good conductor, but locally it may be a poor conductor. The problem is that when general rules - that is to say the standards and codes of practice - are written, they have to cater for all situations. The writers of the standards do not know what the actual situation is on any particular plant where intrinsically safe systems may be installed. So they have to provide for all possibilities.

Where is the Intrinsically Safe Circuit Earthed?

Thus far in this book the only associated apparatus which has been considered is the zener safety barrier. This is quite deliberate because it enables most of the other aspects of intrinsic safety to be explained simply and easily. Consideration of earthing intrinsically safe circuits is no exception.

Consider the simple circuit shown in Figure 10.1

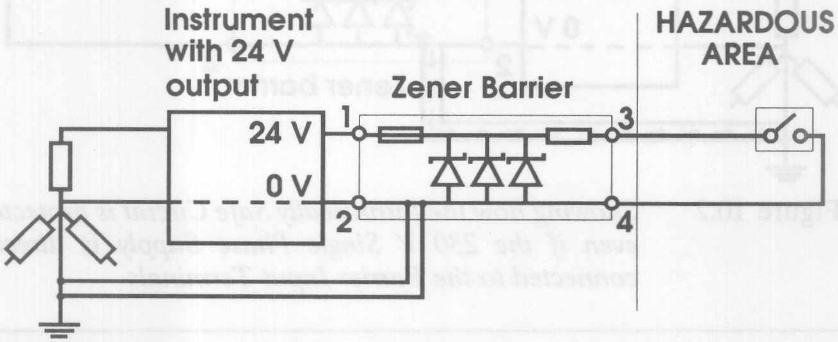

Figure 10.1 *Consideration of Earthing with Zener Barrier Circuits*

Assume that, as shown, the 24 V instrument supply is derived from a normal 'mains' power source, which, in turn, has neutral earth. Assume that, again as shown, the intrinsically safe circuit in the hazardous area (in fact all the circuit from the barrier output) is not connected to earth in any way, but the return side of the barrier (terminals 2 and 4) are connected to earth.

Assume now that there is a fault condition in the 24 V power supply which results in ac mains - rather than 24 V dc - being available at the power supply output terminals and thus at the input terminals to the zener barrier. [1]

Since the zener barrier is connected to earth at the line between terminals 2 and 4, [*] there will be a direct return path via the barrier. The zener diodes in the barrier will continue to protect the integrity of the intrinsically safe circuit whilst this fault occurs (although it will not be long before the fault clears; either by some extraneous fuse or trip, or by the rupture of the fuse in the zener barrier). This position is shown in Figure 10.2.

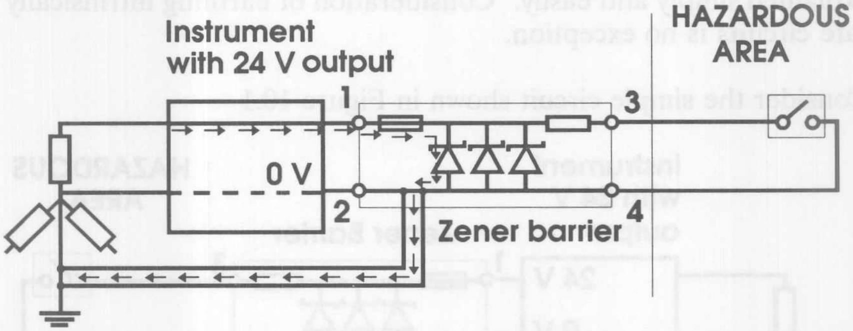

Figure 10.2 *Showing how the Intrinsically Safe Circuit is protected even if the 230 V Single Phase Supply is directly connected to the Barrier Input Terminals*

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* This is, as will be seen, a deliberate connection to earth at this point, quite apart from the possible connection to earth via the return side of the circuit connected to terminal 2.

Alternatively, consider what would happen (with or without the power supply breakthrough fault) if the intrinsically safe circuit in the hazardous area was earthed, as shown in Figure 10.3.

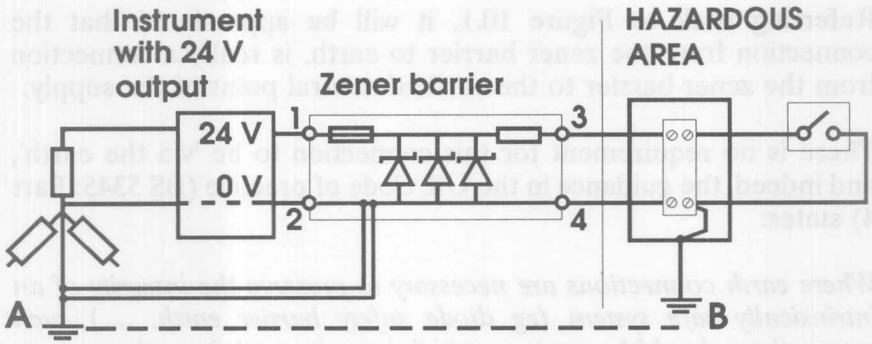

Figure 10.3 *Considering the Dangerous Position if the Intrinsically Safe Circuit is Earthed in the Hazardous Area*

If there is a difference in earth potential between the points 'A' and 'B' [*] and there was a breakage of the wire in the intrinsically safe circuit, or a loose connection in the junction box, again incendive sparks could occur.

Thus, with the zener barrier arrangement as shown, there should be only one connection to earth on the whole of the intrinsically safe circuit, and that is the connection at the associated apparatus; the zener barrier.

* This could happen if, for example, the two points are some distance apart and there is, indeed, nothing apart from the earth (soil) connecting the two points together, especially if the soil is dry, or is locally a poor conductor for some reason. Of course, the problem must be caused by some earth fault somewhere, but this may be an earth fault which is unknown, or even outside the control of the site personnel.

Indeed, it is a requirement that **the intrinsically safe circuit in the hazardous area should be capable of withstanding a 500 V rms test voltage to earth or frame of any apparatus.** [2]

Referring back to Figure 10.1, it will be appreciated that the connection from the zener barrier to earth, is really a connection from the zener barrier to the earthed neutral point of the supply.

There is no requirement for this connection to be 'via the earth', and indeed, the guidance in the UK Code of practice (BS 5345: Part 4) states:

Where earth connections are necessary to preserve the integrity of an intrinsically safe system (eg diode safety barrier earth, ...) such connections should be made to a high integrity earth in such a way as to ensure that the impedance from the point of connection to the main power system earth point is less than 1Ω ... The conductor used for the connection should be equivalent to a copper conductor of 4 mm² minimum cross-sectional area.

So that is reasonably clear, apart perhaps from the reference to 'high integrity earth'. The fact to keep clearly in mind here is that what is required is a connection to the main power system earth. The code clearly states that this can normally be achieved by '*connection to a switch room or similar earth bar or by the use of separate earth rods*'. So the high integrity requirement does not mean a 'separate earth'.

What is clearly required, however, is an electrical connection to the power system earth from the point of installation of the zener barriers which is under good control, and which may be inspected and tested *without fear that the connection will be degraded by some*

other use.[*] Therefore the conductor which is performing this earth connection task should be **a conductor which is reserved solely for the purpose of connecting the earth point of the zener barrier(s) to the power system earth.** It is normally perfectly practical to connect to the earth point of a mains in-comer cable or distribution arrangement close to the zener barrier location.

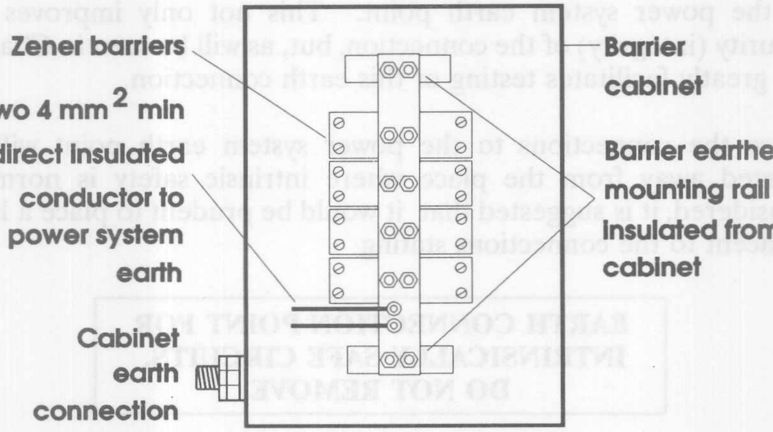

Figure 10.4 *Installation and Earth Connection for Zener Barriers in the Non-Hazardous Area*

It follows, that if the conductor is also connected to the metal work of the cabinet in which the zener barriers are mounted, then it is not only serving the zener barriers, but also acting as the earth

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* For example, to take an extreme condition, if the earth conductor was also serving some motors or other equipment, then there is very little control over its integrity as far as the safety of the intrinsically safe circuit is concerned, because it could be damaged or over-stressed (or in the worst case even burnt out) by faults from other circuits.

connection for the barrier cabinet. So, in order to comply with the requirement that the conductor is reserved solely for the purposes of earthing the zener barriers, it is important that *at the point of installation* the barriers should be isolated from their enclosure, [*] and the conductor used to make the earth connection to the zener barrier(s) should be an insulated conductor. This leads to the installation of the zener barrier as shown in Figure 10.4.

It will be seen that two conductors have been used from the barrier to the power system earth point. This not only improves the security (integrity) of the connection, but, as will be seen in Chapter 15, greatly facilitates testing of this earth connection.

Since the connections to the power system earth point will be located away from the place where intrinsic safety is normally considered, it is suggested that it would be prudent to place a label adjacent to the connections stating

EARTH CONNECTION POINT FOR INTRINSICALLY SAFE CIRCUITS. DO NOT REMOVE

From the preceding discussion it should be apparent that either:

a) the intrinsically safe circuit should be isolated from earth (completely), or

b) be earthed at one point only,

and this is exactly the advice in the UK Code of practice [3] and in the European installation standard. [4]

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* Of course, they are not really isolated from each other at all, since both the barriers and the enclosure will be connected to earth! However, they are not connected until the conductors reach the earth point (switch-room or earth bar).

Earthing of Cable Screens and Armour

Although there is no direct requirement to use screened or armoured cables for intrinsically safe circuits, [*] many users and installers will wish to protect the circuit from risk of electrical interference and/or risk of mechanical damage.

Figure 10.5 shows the correct earthing connections for both screens and armour, and it will be seen that:

- The screen, although through connected along its length, *is only connected to earth at one point* which is at the same point as the earth connection for the intrinsically safe circuit.

  (In other words, for earthing purposes, the screen may regarded as part of the intrinsically safe circuit and should follow the earthing requirements for the intrinsically safe circuit.)

- The armour is connected to earth throughout its length at any point where it passes through a cable gland.

  (The armour is a substantial conductor, and it exists to prevent the cable from being damaged or broken. Therefore it is reasonable to assume that the armour will not be broken, and thus the danger of incendive sparks across a break due to differences in earth potential from one end to the other do not arise.) [**]

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* Indeed, one of the attractions of intrinsic safety is that, because it is known that breaking a wire will not cause an incendive (ignition capable) spark, the normal requirements to mechanically protect the cable to ensure that it will not be damaged may be relaxed. Of course, since cable damage may mean loss of signal, some reasonable protection is still worthwhile and recommended.

** Of course, it is important that there are no loose connections on the armour earthing arrangement, otherwise a potentially dangerous condition could arise.

Notice that the armour, at the non-hazardous area end is electrically connected to the barrier cabinet, and not to the barrier earth bar. Whereas a screen may be considered to be part of the intrinsically safe circuit, the armour is not part of the intrinsically safe circuit, and therefore should not be connected to the barrier earth connection point.

In the case (as shown) where the cable has both screen and armour, it should be able to withstand a 500 V rms test between screen and armour.[5]

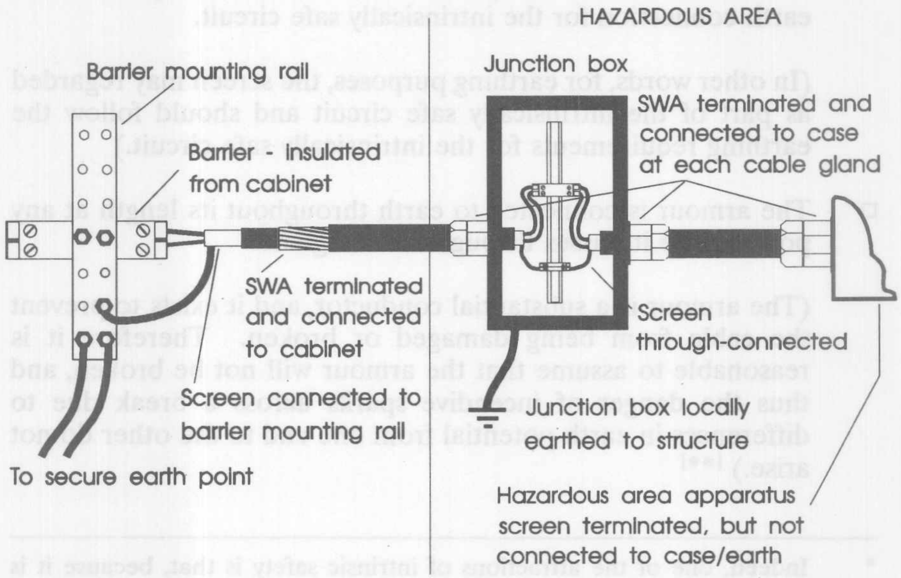

Figure 10.5 *Earth Connections of Screens and Armour*

As far as the armour is concerned, it is really being used as an 'earth equipotential bonding arrangement'. That is, the armour, by being electrically connected to earth at both ends, will help to

ensure that there is no difference in earth potential between one place and another.

On many plants a deliberate effort is made to ensure that all parts of the plant (covering both the hazardous, and non-hazardous area) are electrically bonded together by the use of an equipotential bonding system. In such situations, the danger from possible incendive earth faults is reduced or even removed altogether. Although such an arrangement is not mandatory in the UK, it is becoming more common. In some countries it is a definite requirement. [*]

Arrangements for Circuits which must be Earthed in the Hazardous Area

There are some situations where it is not possible or practicable to maintain a 500 V segregation from earth in the hazardous area circuit. This might happen, for example, with an earth-tipped thermocouple, or some conductivity measuring apparatus which may be earthed via the liquid in a pipe. (Figure.10.6)

There are a number of ways of dealing with this situation.

Firstly, consider a situation where a good equipotential bond exists between the power system earth point in the non-hazardous area, and the earth connection of the intrinsically safe circuit in the hazardous area. Suppose that the connection is of very high integrity and guaranteed minimal resistance. In this situation, there is no danger of potential differences to earth causing possible incendive sparks.

Thus it is normally accepted that the circuit may be connected to earth at both ends if it is assured that there is a separate bonding

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* Although, in the author's experience, not always functionally achieved!

conductor between the two points. The connections to earth or frame of apparatus in the hazardous area, and to the earth point in the non-hazardous area should be such that they will meet the requirements for an increased safety: Ex e connection. [6] The conductor should be substantial, and the distance between the two earth points is normally restricted to 100 m maximum.

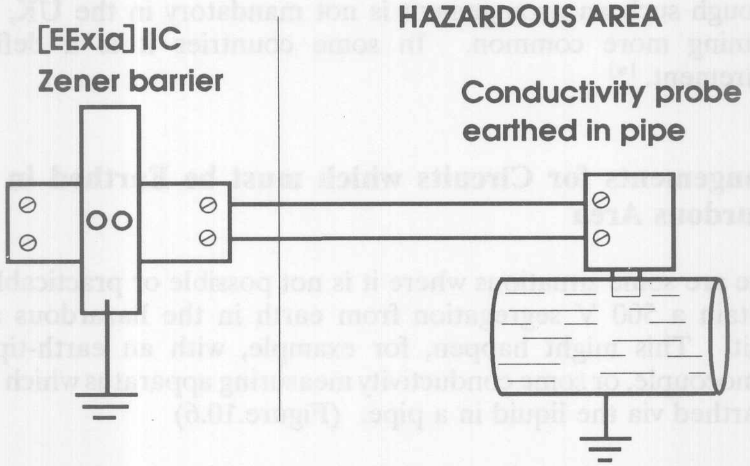

Figure 10.6 *Intrinsically Safe Circuit which is not Insulated from Earth in the Hazardous Area*

If the only interface devices available were zener safety barriers, then there really is not much alternative to this approach. However, as will be seen, other forms of interface such as galvanic isolating interfaces allow a more attractive and probably safer solution.

Secondly, consider the circuit of Figure 10.7. The signal from the

transducer is directly connected to a 4-20 mA transmitter which is located close to the transducer. The transducer includes *a galvanically isolating circuit* such as a transformer, which means that there is no direct electrical connection from one side of the transmitter to the other. In this case, the intrinsically safe circuit may be regarded as two sub-circuits, one of which is earthed at the interface, and one of which is earthed at the transducer. Providing the galvanic separation of the transmitter will withstand a 500 V insulation test, this solution is perfectly acceptable, and many intrinsically safe transmitters which provide such isolation between input and output are marketed.

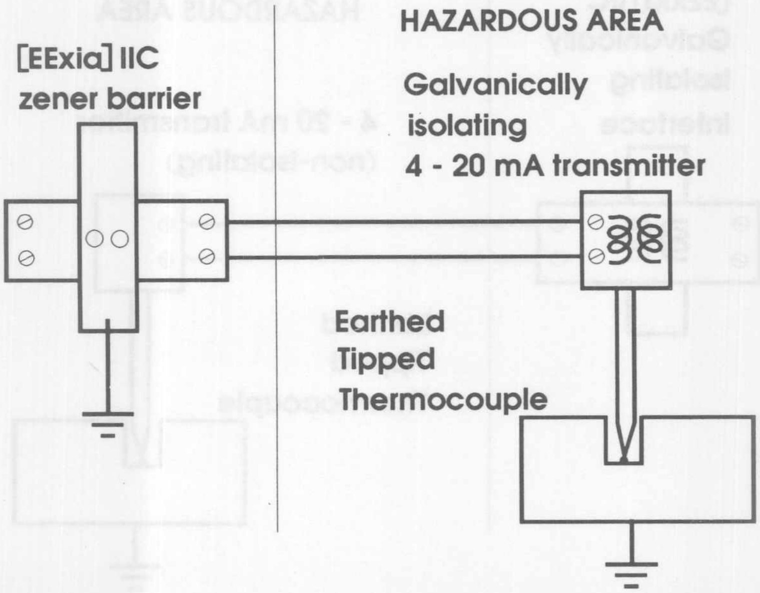

Figure 10.7 *Intrinsically Safe Circuit comprising two Sub-Circuits, each of which is Galvanically Separated and each of which is Earthed at different Points*

Finally, consider the position in Figure 10.8. The galvanic isolation has been brought all the way back to the non-hazardous area, and now forms part of the interface. In other words, the associated apparatus (interface) is now providing both limitation of output to the hazardous area circuit, and galvanic isolation between its input and output terminals. This is the basis of galvanically isolating interfaces, which will be discussed in Chapter 11. This solution is increasing in popularity, and indeed many installations now standardise on galvanically isolating interfaces even where there is no difficulty in obtaining the correct hazardous area isolation from earth.

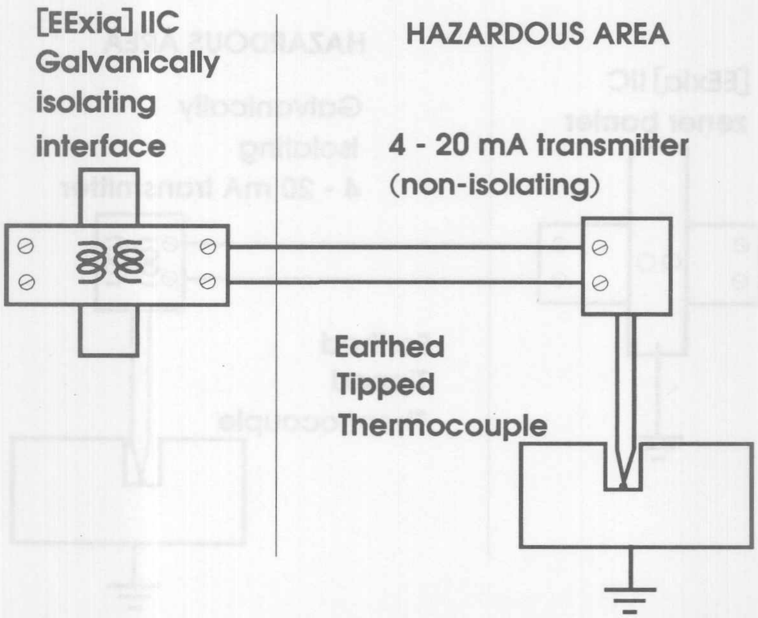

Figure 10.8 *Associated Apparatus which contains Galvanic Isolation*

Indeed, associated apparatus comprising galvanically isolating interfaces is now preferred [7] for circuits which are terminating in zone 0 areas, although zener barriers are acceptable providing the power system is a TN-S arrangement and the earth connection made correctly as previously discussed.

Information on earth testing and explanation of some typical earth fault conditions is covered in Chapters 14 and 15.

SUMMARY

- □ Intrinsically safe circuits should either be isolated from earth or only connected to earth at one point.
- □ Where the interface (associated apparatus) is a zener safety barrier, the intrinsically safe circuit should only be connected to earth via the barrier earth point connection.
- □ Apart from any deliberate earth connections, the intrinsically safe circuit should be capable of withstanding a 500 V insulation test to earth or the frame of any apparatus.
- □ The earth connection from the zener barrier(s) to the power system earth point should be a conductor reserved solely for the purpose of earthing the barrier (thus the barriers should be insulated from the cabinet in which they are housed).
- □ If the hazardous area circuit cannot withstand a 500 volt test to earth/frame of apparatus, galvanic isolation techniques should be used (or, in some circumstances, special equipotential bonding).
- □ If any part of the intrinsically safe circuit is located in zone 0, associated apparatus with galvanic isolation is preferred.

NOTES AND REFERENCES

1. As was shown in Chapter 5, associated apparatus needs to be able to cope with faults like this. The maximum rms ac or dc voltage which may be applied to the non-intrinsically safe (input) terminals of associated apparatus is denoted by U_m.

   For most associated apparatus, values of U_m:250 V are normal. Since this is well above the normal mains voltage with respect to earth, the associated apparatus will clearly be safe for these conditions.

2. The 500 Volt test requirement is examined in more detail in Chapters 14 and 15.

   If an intrinsically safe circuit cannot withstand the 500 V insulation test, it should be assumed that it is earthed.

3. BS 5345: Part 4: Clause 16.3.

4. EN 50 154 clause 12.2.4.

5. The cable should also be able to withstand a 500 volt test between conductors and screen and between conductors and armour. Chapter 12 gives additional information on the requirements for different types of cable and how they are considered in respect of faults between cores etc.

6. See Chapter 2 for more details on the method of protection Ex e: increased safety. In essence, the terminal will need to be mechanically secure and of such design that it will not vibrate loose. See also Chapter 14 for additional information concerning installation of this arrangement.

7. See clause 12.3 of EN 50 154.

CHAPTER 11

Associated Apparatus (2) Other Interfaces

This chapter includes information on
Dual Channel Barriers 'AC' or non-polarity sensitive barriers Isolating Barriers Galvanic Isolators Intrinsically safe power supplies Interfaces incorporated into safe area apparatus

Associated Apparatus - Other Interfaces

In Chapter 5, the basic zener barrier was examined in its simplest form; as a single channel polarity sensitive unit. In this chapter, some variants of the zener barrier and other interfaces will be examined.

Consider the intrinsically safe transmitter loop in Figure 11.1.

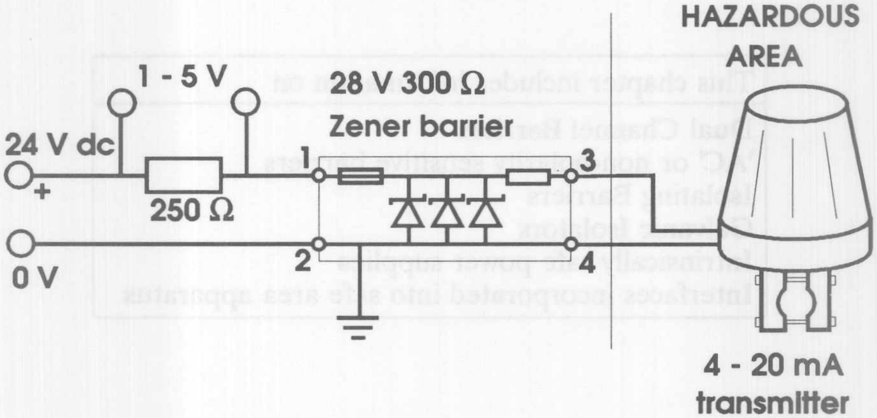

Figure 11.1 *Simple Intrinsically Safe 4-20 mA Transmitter Loop*

The varying current in the loop is converted to a 1-5 V signal across the 250 Ω resistor located on the non-hazardous area side of the barrier. This is a conventional approach with instrument circuits (hazardous area or otherwise) and the voltage signal will be used for control and feedback purposes.

Although this circuit is, for many situations, perfectly adequate, there are a number of possible problems which could give rise to errors in accuracy of the 1-5 V signal.

First, if the voltage on the system is somewhat greater than 24 V, and the zeners in the barrier start to conduct, then current will flow

both through the transmitter and through the zener diodes. The total current will, of course, pass through the 250 Ω resistor and this will lead to an inaccurate signal.

Similarly, an earth fault anywhere in the circuit between the resistor and the transmitter will give rise to false readings.

For these reasons, it would give an improved measurement integrity if the sensing element - the 250 Ω resistor - was placed in the return side of the loop. As the circuit arrangement stands, this cannot be achieved, since the zener barrier is earthed at the line between terminals 2 and 4, and thus if the resistor was simply moved to the return line by terminal 2 of the barrier, there would be no signal to measure. [*]

The first stage in overcoming this problem is to consider using a dual channel barrier arrangement. This is really two barriers back-to-back, as shown in Figure 11.2, with the resulting transmitter loop and re-positioned sensing resistor shown in Figure 11.3.

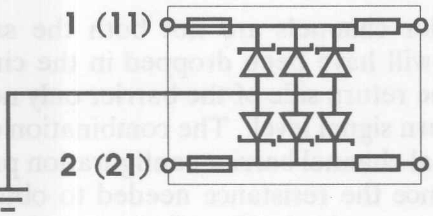

Figure 11.2 *Dual Channel Barrier (positive polarity)*

(Alternative terminal numbering shown in brackets) [1]

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* This explanation assumes that the supply for the arrangement is negative earthed at some point. If the supply is not negative earthed, then it should be appreciated that by the introduction of the barrier the negative side will be pulled to earth anyway via the barrier earth connection. (See Chapter 10 on earthing.)

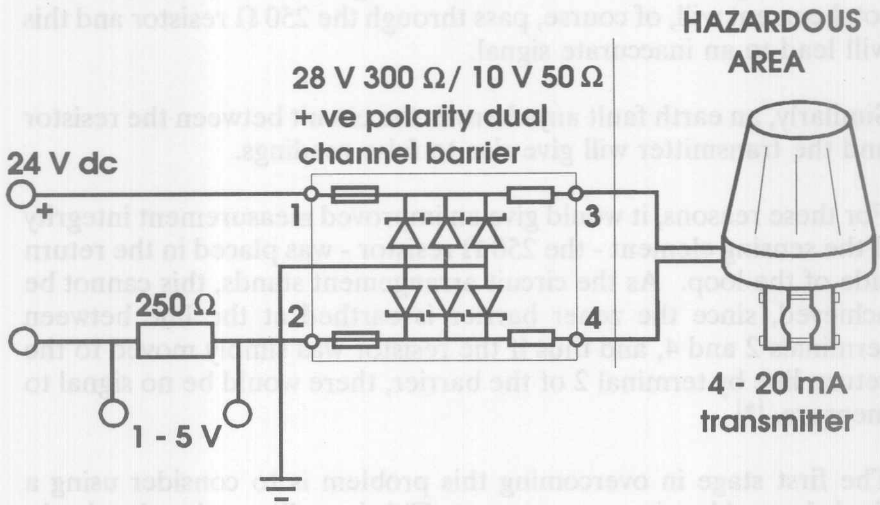

Figure 11.3 *Intrinsically Safe Transmitter Loop using Dual Channel Barrier*

Notice that the barrier channels are not both the same rating. Considerable voltage will have been dropped in the circuit by the return leg, and thus the return side of the barrier only needs to give protection for the return signal level. The combination of 28 V and 10 V is a 'standard' dual channel barrier configuration produced for such applications. Since the resistance needed to obtain intrinsic safety to the resistive curves is significantly less at 10 volts than at 28 volts, the resistance of the barrier is reduced from 300Ω to 50Ω.

In spite of this reduced resistance, the overall resistance of the circuit is not insignificant and needs some careful consideration.

The end-to-end resistance of the 28 V channel comprises the resistance of the barrier internal fuse, possibly about 10 Ω, and the 300 Ω resistance, which, allowing for maximum tolerance and remembering that it has been stated to be 300 Ω *minimum*, may

well be 330 Ω. Thus the overall resistance of the 28 V channel could be as much as 340 Ω. [*] Similarly, the end-to-end resistance of the 10 V channel may be as much as 80 Ω.

Most modern 4-20 mA transmitters are not so 'volt hungry' as they were a few years ago, but it is still not uncommon to find that the transmitter needs 12 V or so to actually operate.

Assume the circuit is drawing 20 mA, and examine the circuit current as follows.

Total resistance in circuit (worst case)

= R(28 V barrier channel) + R(10 V barrier channel) + R(sensor [250 Ω]) + R(cable)

= 340 + 80 + 250 + 10

= 680 Ω

At 20 mA, volt drop across 680 Ω = 13.6 V

But this means that there are only 10.4 volts available for the transmitter, and if it needs 12 V to operate, the circuit will not work correctly. [**]

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* For most modern barriers, this is probably a worst case, and the quoted maximum end-to-end resistance of most 28 V 300 Ω barriers is 330 Ω. However, with some of the older designs, utilising a two diode assembly, with a central resistor to facilitate manufacturer's testing, end-to-end resistances of 350 Ω are not uncommon.

** This is a classic problem. What often happens is that the circuit appears to work correctly, but will never actually draw more than about 16 mA. That is, the measuring loop will never read full scale. If, due to poor calibration and commissioning, the loop has never been fully tested throughout its range, the fault may go unnoticed and could be extremely dangerous from a functional viewpoint if the top few % of the range equates to, for example, an over-temperature in the process.

(Of course, if the transmitter only requires about 9 volts to function, then, even with this worst case resistance, all will be well.)

Because this problem is well known, it has been addressed by the barrier manufacturers. The solution is the barrier configuration shown in Figure 11.4

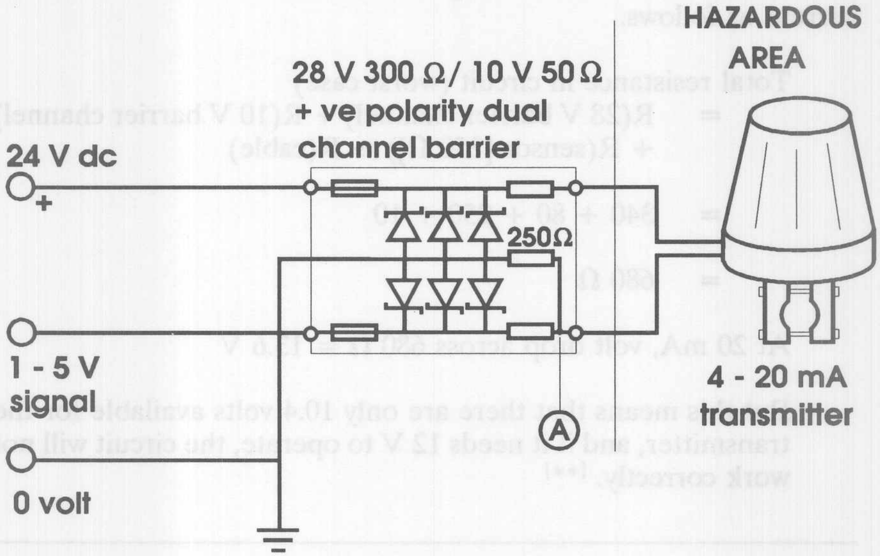

Figure 11.4 *Intrinsically Safe Transmitter Loop using Dual Channel 28 V 300 Ω / 10 V 50 Ω Barrier with Integral 250 Ω Resistor*

Assuming that the 1-5 volt signal is 'seeing' a high impedance, then the resistor can be moved to the output terminals of the barrier. The voltage signal, with respect to 0 V will be sensed at point 'A', but no current will be drawn through the return barrier channel, and thus the resistive consideration is improved by up to 80 Ω.

This solution is normally adequate, unless very long cable runs, or unusually high resistance cables are being used.

The barrier manufacturers produce the barrier arrangement shown, with the sensing resistor incorporated into the assembly. [*]

There are a number of special purpose barriers produced, and it should be appreciated that whereas the basic single channel configurations have wide and diverse uses, the more complex arrangements are normally designed for a specific application.

The permitted combinations of barrier channels into one circuit are normally covered by system certificates and the barrier manufacturers will normally provide this data on request.

A similar situation to that discussed above for the 4-20 mA circuit leads to a dual channel barrier for switching applications known as a 28 V 300 Ω / 28 V diode return barrier. This is shown in Figure 11.5, and the intended operation using a simple relay is shown in Figure 11.6.

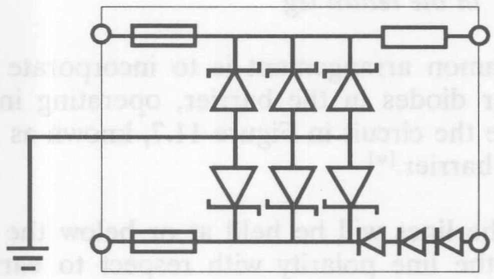

Figure 11.5 *Circuit of a 28 V 300 Ω / 28 V Diode Return Barrier (positive polarity)* [2]

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* The barrier type number for such arrangements normally ends with the letter 'R' to denote the presence of this internal resistor.

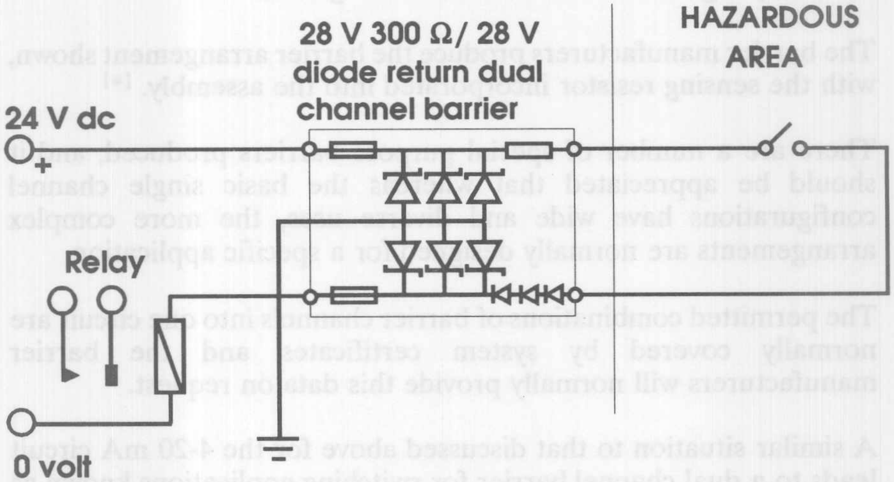

Figure 11.6 *Intrinsically Safe Circuit Loop for a Switch, using the 28 V 300 Ω / 28 V Diode Return Barrier with the relay in the return leg*

A further common arrangement is to incorporate an additional series of zener diodes in the barrier, operating in the opposite polarity to give the circuit in Figure 11.7, known as a non-polarity barrier or AC barrier.[*]

In this case, the lines will be held at or below the zener voltage regardless of the line polarity with respect to earth. In either polarity, one of the zeners in each chain will be presented in the forward direction, thus contributing only their forward volt drop of about 0.6 V, and the other zener in the chain will operate in the zener direction.

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* Although the terms AC barrier is commonly used, it is rare, if ever to find a true AC application. (Many signals vary around a norm, but they rarely change from positive to negative *with respect to earth*.)

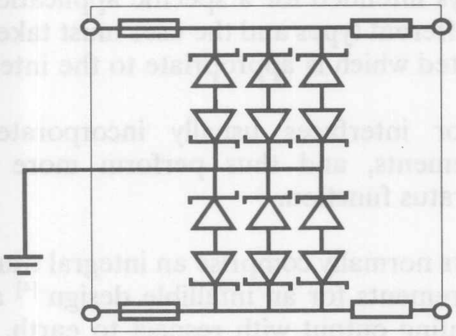

Figure 11.7 *Basic Circuit of a Non-Polarity Sensitive or 'AC' Dual Channel Barrier*

Applications for dual channel barriers include some temperature measuring elements, bridge circuits etc. Non-polarity barriers are normally only available for low voltages; typically for 10 V barriers and below.

It should be appreciated that in all the foregoing examples, although the return line is served by a second barrier channel, the circuit is still related to earth via the barrier arrangement. Thus dual channel barriers do not provide, and are not suitable for, fully floating systems. [3]

Galvanic Isolators

As has been seen in preceding chapters, there are occasions where it is convenient to have an interface which does not result in referencing the circuit to earth. Such interfaces are now increasingly common, and fall under the heading of isolating (or galvanically isolating) interfaces.

Again, it is important to note that galvanically isolating interfaces

are almost always intended for a specific application. Thus there are very many different types and the user must take care to ensure that one is selected which is appropriate to the intended use.

Galvanic isolator interfaces usually incorporate some signal conditioning elements, and thus perform more than just the associated apparatus function.

Galvanic isolators normally comprise an integral transformer which meets the requirements for an infallible design [4] and which thus gives a fully floating output with respect to earth. This supply - rectified - is then voltage and current limited - often using both conventional zener voltage clamping and resistance current limiting as well as transformer saturation techniques. [*] This drives the hazardous area intrinsically safe circuit, and the output signal is further isolated by means of component certified opto isolators. The resulting circuit is shown in simplified form in Figure 11.8.

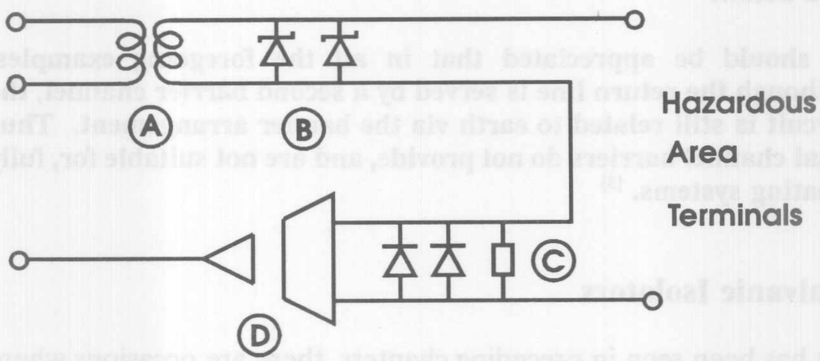

Figure 11.8 *Basic Circuit for a Galvanic Isolator Interface for a 4-20 mA Circuit*

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* There is nearly always some resistance current limiting, because the standards do not permit series semiconductor current limiting for 'ia' circuits.

Explanation of Figure 11.8

Transformer 'A' provides galvanic isolation from the non-hazardous area terminals. The transformer output is rectified (not shown) and then subjected to additional zener diode clamping 'B'. The current in the hazardous area circuit is sensed across resistor 'C' and converted by circuitry 'D', which includes further galvanic isolation (possibly opto isolator) to the output signal for non-hazardous area use.

For switching applications, a relay, conforming to segregation requirements for intrinsic safety is incorporated within the unit, giving the circuit shown in Figure 11.9.

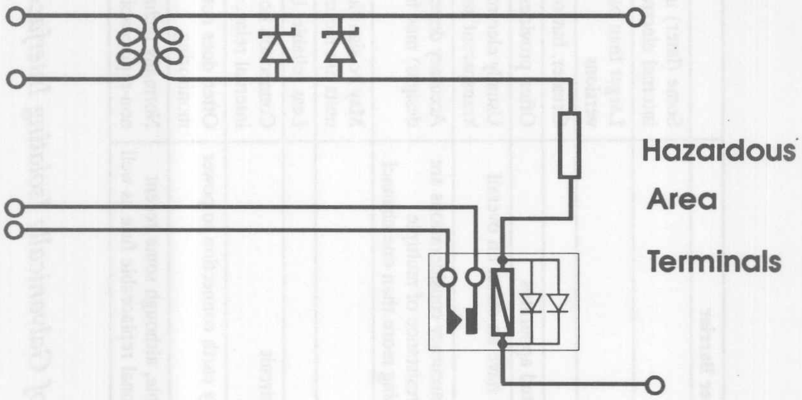

Figure 11.9 *Basic Circuit for a Galvanic Isolator Interface for a Switch Circuit*

The advantages and disadvantages of these interfaces compared with the standard zener safety barrier are shown in Table 11.1.

	Zener Barrier	Galvanic Isolator
Power requirements	'Passive' device	Some (later) units loop powered but some require power to operate internal electronics
Physical size	Small	Larger than barrier but loop powered versions smaller than powered versions
Cost	Low	Greater, but often for more complex function
Function	Only provides associated apparatus	Often provides signal conditioning in addition to associated apparatus
Signal attenuation	In line resistance may have an effect on overall circuit loop	Usually electronically compensated such that unit appears electrically 'transparent' to signal - but there are accuracy considerations
Accuracy	Passive device. Only accuracy considerations are matching end-to-end resistance of multiple channels in circuits using more than one channel	Accuracy dependent on internal circuit. Some types (especially earlier designs) may be poorly affected by temperature variation
Heat dissipation	Insignificant	May be significant due to internal power supply especially if several units are mounted close together
Reliability	More reliable	Less reliable, but probably not significant for most applications
Safe area connections	Direct connection to circuit	Connection normally provides signal function, eg switched output from internal relay, or 4-20 mA current signal
Earthing	Requires high integrity earth connection to power system earth	Often does not require any earth connection except for earth fault monitoring
Fuse	Internal non-replaceable, although some recent designs include additional replaceable fuse as well	Normally includes replaceable fuse (although there is still an internal non-replaceable fuse)

Table 11.1 *Comparison of Galvanically Isolating Interfaces and Zener Safety Barriers*

It will be seen from the preceding diagrams that these devices require a power supply separate from the circuit measuring terminals. That is to say, they are not loop powered. This is simply because the unit itself requires some power to drive the electronics within the unit. More recently, loop powered galvanically isolating interfaces have become available. These units really give all the advantages of the isolator, but do not need a separate supply to drive them.

Although most galvanic isolation interfaces are designed to give output levels which will not allow the intrinsically safe circuit to dissipate in excess of 1.3 watts, and thus will automatically give an output which will satisfy the T4 requirement, [5] some such units may be capable of providing more power. [6] Care should always be taken when assessing temperature considerations of intrinsically safe apparatus, especially simple apparatus, used with certain galvanic isolators.

Intrinsically Safe Power Supplies

Sometimes, the associated apparatus is actually combined with a power supply unit to give an intrinsically safe power supply. At one stage, intrinsically safe power supplies became quite popular, but, especially with the increased use of galvanic isolators, their popularity has declined.

Some intrinsically safe power supplies were based on a constant current output, which allowed the rated current to be available in the load at the rated output voltage. It will be appreciated that such an output is not, in terms of the ignition curves, a resistive source, and thus the minimum ignition curves for resistive circuits do not apply. Alternative curves for constant current sources have been proposed from time to time, but although experimental curves do exist, they are not used for certification purposes.

Users of intrinsically safe power supplies should always take great care to ensure that the intended use is within the certification conditions. Among the common problems are:

difficulty in defining cable parameters

wattage dissipation and thus T-classification of the load

output parameters of U_o ($U_{max\ out}$) and I_o ($I_{max\ out}$)

many such supplies are only 'ib' rated, because they have semiconductor (rather than resistance) current limiting.

Safe Area Apparatus with built-in Associated Apparatus

Some specific applications use safe area apparatus which has its own built-in associated apparatus. In this instance, the safe area apparatus must be certified as associated apparatus, and will include a certification label with the certification code in brackets as previously noted.

The disadvantage of this approach is that the safe area apparatus (or at least part of it) is now a certified design and cannot be changed without reference back to the nominated body. Furthermore, it prevents a ready identification of where the associated apparatus is located, since it is quite normal for all the associated apparatus (eg all the zener barriers or all the galvanic isolating interfaces) to be mounted in one or more cabinets on the plant.

SUMMARY

- Dual channel barriers allow the sensing of control operation to take place in the return leg of the loop. This gives greater accuracy and overcomes some error conditions.

- The use of dual channel barriers does not produce a true floating circuit. The barrier is still connected to earth and thus the circuit is still related to earth.

- Galvanic isolators (normally employing transformer and opto coupling techniques) do give fully floating solutions and do not normally require an earth connection for intrinsic safety purposes.

- Galvanic isolators are normally intended for a specific application or task, and are not general purpose interfaces like the zener safety barrier.

- If the safety interface is built-in to the safe area apparatus, that apparatus will have the certification label showing it to be (or contain) associated apparatus.

NOTES AND REFERENCES

1. Dual channel barriers may use either terminals 1-2-3-4 or 11-13 (indicating terminals '1' and '3' of the first channel) and 21-23 (indicating terminals '1' and '3' of the second channel.)

   Most recent designs of dual channel barrier seem to be standardising on 1-2-3-4, and since both the single and dual channel units are normally of the same physical size, it is clearly important that the installer reads the label carefully to differentiate between a single and dual channel barrier.

2. Note that there are three series blocking diodes in the return line to comply with 'ia' requirements.

3. For information on earth fault monitoring refer to Chapters 14 and 15.

4. The design of infallible transformers is covered in more detail in Chapter 13 on intrinsic safety design.

5. See Chapter 6.

6. The maximum output power from associated apparatus is termed P_o in the second edition of EN 50 020 (or $P_{max\ out}$ for apparatus certified to edition 1 of EN 50 020), and this value will, if appropriate, be marked on the certificate and label as well as U_o etc. Similarly, intrinsically safe apparatus may bear information on P_i (or $P_{max\ in}$) - the maximum input power which can be dissipated without invalidating intrinsic safety.

CHAPTER 12

Cables and Cabling for Intrinsically Safe Systems

This chapter includes information on
Cable types and fault considerations Cable parameters and their calculation Mechanical and electrical protection of cables Multicore cables PVC cold flow Types of cable which may be used

NOTE
The information in this chapter concerns cables for the interconnection of apparatus in intrinsically safe systems. Wiring used within apparatus is covered in Chapter 13.

Cables and Cabling for Intrinsically Safe Systems

Intrinsic safety achieves its protection by maintaining electrical power at levels which are less than the minimum ignition level. This being so, even if a cable is cut or damaged, *providing the cable only contains an intrinsically safe circuit* any spark at the break will not be ignition capable.

Thus for intrinsically safe circuits, the normal requirement, applicable to installations using other methods of protection, that the cable be suitably protected against the risk of ignition due to breaks and damage, can be relaxed.

For many intrinsically safe applications this is one of the major advantages, since considerable savings can be made on cable costs and installation costs if heavy steel wired armoured cables etc. are not required. [*]

There are, however, some considerations for cables in intrinsically safe circuits.

Cable Capacitance and Inductance

Cables exhibit capacitive and inductive properties. Therefore, the interconnecting cable used in an intrinsically safe system may itself present a source of stored energy. This aspect was discussed briefly in Chapter 9 on system considerations.

Since the energy stored in a capacitor = $\frac{1}{2}CV^2$, it will be clear that capacitive stored energy will tend to be a greater consideration at higher voltages. In intrinsic safety terms, this means at voltages

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* Of course, sometimes the potential loss of a signal is considered critical to the process, and thus mechanical protection may be required anyway.

above around 20 V (for example, circuits operating via 22 V and 28 V interfaces). As explained earlier in the book, as the voltage decreases, so the permissible safe current for intrinsic safety increases. Thus the lower voltage interfaces tend to have lower series resistance and will allow more current into the intrinsically safe circuit. Since the energy stored in an inductor is $\frac{1}{2}LI^2$ it follows that inductive problems with cables tend to occur with lower voltage circuits (typically those operating from 1, 4 and 10 V interfaces).

It is rare that there will be both capacitive and inductive problems in the same circuit. Furthermore, it is unlikely that either cable capacitance or cable inductance will approach the limiting values with cable lengths of less than about 1 km.

Cable parameters are normally quoted on system certificates for intrinsic safety and, as would be expected, the permissible maximum values are dependent on the gas group of the installation. [*] Until the publication of the second edition of EN 50 020 the minimum ignition curves for capacitance only gave values applicable to group IIC (see Chapter 13, Figure 13.5). The levels applicable to gas groups IIA and IIB were taken to be 8 times and 3 times the IIC levels respectively.

The capacitive curves have been significantly altered at the second edition of EN 50 020 and, as will be seen from Appendix 1, now show maximum permitted capacitance for each gas group. [1]

Cable capacitance will vary according to conductor size, distance of core separation and the insulation of the cores (the dielectric). The resistance of the cable has little effect on its capacitance and is ignored for capacitive purposes. Typical values of capacitance for an instrumentation cable would be about 100 pF per metre.

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* If necessary, refer back to Chapter 9 at this point to see the relationship between minimum ignition levels for the different gas groups.

(Additional cable data is given in Appendix 7.)

Maximum cable inductance can be expressed as an inductance to resistance ratio as seen in Figure 9.3 in Chapter 9. If the only inductance in the circuit is the inductance of the interconnecting cable, then the inductive stored energy will be at a maximum when the cable resistance equals the source resistance. Thus the worst case (maximum) L/R ratio is defined by the condition where the cable resistance equals the source resistance.

If cable parameters are not available from a system certificate, and need to be calculated, proceed as follows.

A Circuits containing only simple apparatus and one item of associated apparatus

Note the values of C_o and L_o (or $C_{max\ out}$ and $L_{max\ out}$) assigned to the associated apparatus and marked on the apparatus label and in the certificate.

Unless the simple apparatus has been defined under the rules of the second edition of EN 50 020 as containing some capacitive or inductive properties, then all the permitted capacitance and inductance is allowed for the cable parameters.

If the simple apparatus does have some capacitance or inductance, then this must be subtracted from the associated apparatus permitted values, with the remainder being the cable parameters.

The value for cable inductance to resistance ratio may be obtained, *for circuits where the associated apparatus provides a resistance limited power source* by the following formula. [2]

Cable L/R ratio =

$$(8eR_i + (64e^2R_i^2 - 72U_o^2eL_i)^{0.5})/4.5\ U_o \qquad (H/\Omega)$$

where

e is the minimum spark-test apparatus ignition energy in joules and is

525 µJ for group I application
320 µJ for group IIA applications
160 µJ for group IIB applications
40 µJ for group IIC applications

R_i is the minimum output resistance of the power source (associated apparatus) in ohms

U_o in the maximum open circuit voltage in volts

L_i is the maximum inductance present at the power source terminals in henries

If $L_i = 0$, then the formula reduces to

Cable L/R ratio =

$$3.55\ .\ (eR_i/U_o) \qquad (H/\Omega)$$

B Circuits containing one item of associated apparatus and one or more items of certified intrinsically safe apparatus

Total the noted values of C_i and L_i (or C_{eq} and L_{eq}) for each item of intrinsically safe apparatus in the circuit. Add in the capacitance and inductance applicable to any simple apparatus. Subtract the result from the permitted capacitance and inductance C_o and L_o (or $C_{max\ out}$ and $L_{max\ out}$) of the associated apparatus. The remainder is the permitted maximum cable capacitance and inductance.

C Circuits containing more than one item of associated apparatus

Such circuits will require careful assessment of a number of aspects such as the power which can be transmitted to the circuit under maximum output conditions of all the associated apparatus. Thus it is extremely unlikely that such arrangements will not be the subject of a system certificate or at the very least a comprehensive system drawing [3] compiled by the supplier or manufacturer of the associated apparatus or the intrinsically safe apparatus. The documentation should state the applicable cable parameters.

Measurement of Cable Capacitance and Inductance

Values of cable capacitance and inductance are normally available from the cable manufacturers, but if measurement of a sample is necessary, then it is recommended that capacitance should be measured with a capacitive bridge or measuring instrument operating at between 1 kHz and 10 kHz. Similarly, cable inductance is best measured at 1 kHz. Measurement of a 10 m length will normally give sufficient accuracy to determine the applicable values for the actual length desired. Since it may be assumed that cable resistance is directly proportional to length, such a sample will also enable the critical length of cable, at which the cable resistance will equal the output resistance of the associated apparatus (the source resistance), to be determined.

In the rare circumstances where it is necessary to measure capacitance or inductance of an installed cable in the hazardous area, the measurement should be taken on the non-hazardous area side of the associated apparatus, and will only be possible if a zener barrier is being used as the associated apparatus. The results obtained must be corrected for the effects of the zener barrier capacitance and inductance. [4]

Requirements for Cable Conductor Size, Insulation etc.

The advice of the various standards and codes of practice for intrinsic safety vary slightly for general cable consideration. However, the main aspects are as follows.

The conductors in the interconnecting cable should be sufficient for the current of the intended application and be such that any heating effect of the cable will not cause the temperature classification of the system to be exceeded. In practice, this will rarely be restrictive, and normal cables used in instrumentation systems will adequately meet the requirements.

The UK Code of practice (BS 5345: Part 4: 1977) includes the following table which relates to copper conductors and shows the minimum conductor size required for a T4 rating (thus also suitable for T1, T2 and T3).

Maximum current (A)	1.0	1.65	3.3	5.0	6.6	8.3
Minimum cross sectional area of conductor (mm^2)	0.017	0.03	0.09	0.19	0.28	0.44

Table 12.1 *Minimum Conductor Sizes for T4 Cable Rating*

The code also states that conductors of interconnecting cables should be insulated with thermoplastics or elastomeric material of minimum [radial] thickness of 0.3 mm, [5] or be mineral insulated. The cable should be capable of withstanding, between cores, or between any core and screen, a test voltage of 500 V rms without breakdown. Any overall screen should also be insulated from an external conductor; eg the cable tray.

Multicore Cables

The golden rule to remember at all times is that intrinsically safe and non-intrinsically safe circuits should never share the same multicore cable.

The CENELEC system standard [6] identifies four types of cable and, for each type, states whether or not faults between differing circuits need to be considered from an intrinsic safety viewpoint. The cable types are as follows.

Type A cables must

a) be specified in the intrinsic safety descriptive system document.

b) not contain any non-intrinsically safe circuits

c) have core insulation appropriate to the conductor diameter and the type of insulation.

d) have core insulation which will withstand a 500 V insulation test (or twice the voltage of the intrinsically safe circuit if this value is greater than 500 V).

e) where conducting screens provide individual protection for intrinsically safe circuits, the coverage of the screen shall be at least 60% of the surface area.

f) shall be capable of withstanding an rms ac dielectric strength test of

500 V between any armouring and/or screen joined together and all cores joined together

1000 V applied between a bundle comprising one

half of the cores joined together and the bundle comprising the other half of the cores joined together.

If each circuit is enclosed in an individual conducting screen, faults between circuits need not be considered.

Type B cable is cable which is fixed in position, and complies with a), b), c), d), and f) above - not necessarily complying with e).

Failures between circuits are not considered unless any circuit has a peak voltage exceeding 60 V.

Type C cable is cable as specified for Type B, but is not fixed in position.

Up to two connections between conductors with, simultaneously, up to four open circuit conductors shall be considered.

Type D cable is cable complying with a) and b) above.

There is no limit to the number of connections and simultaneous open circuits which must be considered and shown to be safe.

Normally, the simplest approach is to comply with the requirements of cable Type A and thus avoid considering the effects on intrinsic safety of faults between differing circuits.

It is worth noting that these requirements are, in practical terms, very similar to the requirements of the UK Code of practice (BS 5345: Part 4: 1977) which states that faults between differing circuits in a multicore need not be considered unless any of the circuits terminate in zone 0, providing:

a) the multicore cable is run where risk of mechanical damage is low, or else given additional mechanical protection

b) the cable is firmly fixed throughout its length

c) each intrinsically safe circuit contained in the multicore cable occupies adjacent cores throughout its length

d) no intrinsically safe circuit contained within the multicore operates in normal or fault conditions at more than 60 V.

Invasion of Intrinsically Safe Circuits

Interconnecting cables of intrinsically safe circuits may be run in the same ducting or tray as other cables, provided that either the intrinsically safe cables or other cables are armoured or metal sheathed. Armouring or metal sheathing is not, however, required in locations where risk of mechanical damage is slight (eg in ducting in a control room) but in such cases both types of cable should be insulated and sheathed.

A few moments thought on the above paragraph, which is taken from the UK Code of practice, will lead to the realisation that, as stated at the outset of this chapter, there are few restrictions on the mechanical protection of cables for intrinsically safe circuits. The CENELEC installation standard [7] has a clause giving a similar meaning.

Induction into Interconnecting Cables of Intrinsically Safe Circuits

Induction into interconnecting cables at a level which could lead to a significant reduction in safety has been shown to be extremely unlikely in most practical situations. Significant induction could,

however, occur if interconnecting cables are sited parallel to and close to overhead power distribution lines or heavy current carrying single core cables. Accordingly, care should be taken to avoid siting cables containing intrinsically safe circuits close to such cables and lines.

Again, this paragraph, taken from the UK Code of practice, neatly summarises the position and indicates that there is very little real problem. The CENELEC installation standard gives the same advice and states that where the adverse effects of external electric or magnetic fields cannot be avoided by the siting of cables containing intrinsically safe circuits, the use of screens and/or twisted cores may be employed.

PVC Cold Flow

PVC insulation, when compressed (as it will be when tightened in a cable gland) can flow away from the point of compression. This phenomenon is known as cold flow and sometimes affects cables quite significantly. The problem normally manifests itself when some cable glands, which have been recently installed and correctly tightened, are inspected and found to be loose on the cable clamp.

Some cables exhibit cold flow characteristics much worse than others. Low smoke emission (LSF) cables may be especially susceptible.

Although cold flow can clearly cause the environmental protection of an enclosure to become degraded, it is much less of a problem with intrinsic safety than with other methods of protection since intrinsic safety is not actually relying on the integrity of the enclosure to achieve its protection against ignition. However, the ingress of water into an enclosure may well degrade the equipment operation, or give rise to poor insulation resistance, so cold flow problems should be carefully monitored.

Cable manufacturers can normally give reasonable information on cold flow characteristics of their products.

PVC Cables at Low Temperatures

PVC becomes increasingly brittle as temperature decreases. Below 0°C the problem sharply increases in severity, and in some cases at low temperatures, if the PVC is bent sharply or struck, the PVC can crack. If PVC cable has been stored at a low temperature, it should be allowed a good time - often as much as 24 hours - at a temperature above 0°C before being run off the cable drum and used.[*]

Cable Identification and Colour

Cables carrying intrinsically safe circuits should be identified as such. This may be achieved by marking or by the use of light blue sheathed cable. **The colour light blue is often used to indicate intrinsic safety** and is permitted by standards such as EN 50 020 and EN 50 154.

Where there is a possibility of intrinsically safe and non-intrinsically safe wiring and cables existing in close proximity (for example within a control panel), care should be taken to avoid the possibility of a blue neutral conductor on a non-intrinsically safe circuit being mistaken for an indication of intrinsic safety. This may necessitate additional marking and/or bundling of cables in some locations.

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* Beware of cables left overnight on site during installation work. Cable pulling gangs may not be aware of the damage they are causing and the problem will not become apparent until much later on.

SUMMARY

- Cable capacitance and inductance (or L/R ratio) needs to be considered in intrinsically safe circuits - although it is rarely a problem unless cable is long.
- Intrinsically safe and non-intrinsically safe circuits must never be run in the same multicore cable.
- Most cables qualify for T4 rating.
- Cable insulation should be able to withstand a 500 V insulation test.
- Beware PVC cold flow which can cause cable glands to not seal properly.
- Beware damage to PVC cables at low temperatures.

NOTES AND REFERENCES

1. It should be noted that the actual values have changed as well. That is to say, using the old curves for group IIC, and then multiplying the value by 3 or 8 for the IIB and IIA values will not give the same result as using the new curves. In general, the new curves will result in more capacitance being permitted.

   It follows that some existing system certificates are stating maximum permitted cable capacitance levels which are unduly restrictive. It should, however, be borne in mind that a certificate is not valid if it is departed from in any way, and thus users should beware of making their own amendments to stated cable capacitance levels. If necessary, a variation to certificate should be sought. In practice, as has been indicated, cable parameters are rarely a problem, so the requirement to squeeze every last bit of permitted capacitance by adopting the new curves on an existing certificate is unlikely to be necessary.

2. See clause 6.3.3 of EN 50 020, second edition.

3. It should be noted that there is, in any case, a requirement that a 'descriptive system document' should be prepared by the system designer. The applicable limits and restrictions of the system, including cable parameters should be specified in this document.

4. A dual channel 'AC' zener barrier such as 2 V 5Ω or 4 V 10Ω is normally suitable for use with capacitance and inductance bridges.

5. EN 50 039 and EN 50 154 specify 0.2 mm minimum radial thickness for normal insulating materials (polyethylene etc). However, the minimum radial thickness of 0.3 mm specified in the UK Code of practice is achieved by most suitable cables anyway.

6. EN 50 039. Electrical apparatus for potentially explosive atmospheres. Specification for intrinsically safe electrical systems 'i'.

7. EN 50 154. Electrical installations in potentially explosive gas atmospheres (other than mines).

CHAPTER 13

Intrinsic Safety Design

This chapter includes information on
Use of intrinsic safety resistive curves Use of intrinsic safety capacitive curves Use of intrinsic safety inductive curves Assessment of intrinsic safety capacitance and inductance Assessment of temperature classification Creepage and clearance Use of casting compound (encapsulation) Infallible components Connections and wiring in intrinsically safe circuits Temperature classification of wiring and printed circuit tracking Portable apparatus Piezoelectric devices Cells and batteries

NOTE

The information in this chapter is intended to guide prospective designers of intrinsically safe circuits as to the main requirements. The appropriate standards such as EN 50 014, EN 50 020 should always be consulted before detailed assessment or design work is commenced.

Intrinsic Safety Design

This chapter explores the basic requirements of intrinsic safety design.. It will be of interest to those readers involved with apparatus design and certification. Readers who use apparatus, or design circuit loops (systems) using apparatus which is already certified and provided by other equipment manufacturers may safely skip this chapter.

Four Main Principles for IS Design

The four key considerations for intrinsic safety design are:

- □ Is the voltage and current required for the apparatus within the limits imposed by the resistive curves?
- □ Is the maximum capacitance in the circuit within the limits imposed by the capacitive curves?
- □ Is the total inductance within the limits imposed by the inductive curves?
- □ Will the apparatus design give any problems with surface temperature for the T-Classification required?

Clearly, within these four considerations there are a number of other aspects which need to be considered, and these will become apparent as the design concept is explored.

Resistance Curves

A glance at the resistance curves for intrinsic safety (Appendix 1) tends to give the impression that quite high voltages are permitted at low currents and vice versa. However, it is impossible to exclude capacitance and inductance considerations, since the apparatus will

need some cable to connect it to other apparatus or to the associated apparatus. [*] This means that the capacitive and inductive curves can rarely be ignored altogether, and thus the useful part of the resistive curves is that hatched portion shown in Figure 4.1. (Chapter 4)

The first stage in intrinsic safety design is to check that the intended circuit will operate within these limits. Although it may be possible in some situations to utilise the curves at higher voltages or currents, this will cause major difficulty with certification and should be avoided if at all possible.

A good guide at this early stage is to consider what associated apparatus is to be used to connect the intrinsically safe apparatus to the non-hazardous area. Although it is perfectly possible to design a custom built interface for the apparatus, most designers prefer to use a proprietary interface because

a) it reduces certification costs and time

b) many end users standardise on one manufacturer of interface and if the apparatus requires a special interface it will be harder to market.

The main manufacturers of interface units such as MTL, Pepperl and Fuchs, Safety Technology - Weidmuller have an extensive range of interface products and if the intended design will not operate satisfactorily from any of the readily available interface units there is probably something wrong!

When checking the design against the resistive curves, remember that the voltage to use is the maximum circuit voltage (U_o or U_z of the associated apparatus) and remember to apply a factor of safety of 1.5 to the current.

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* A possible exception to this statement is with self-contained portable apparatus which is not part of a system.

Capacitive and Inductive Curves

When assessing the circuit to the capacitive curves (see Appendix 1) the best approach is as follows.

To determine maximum voltage for given capacitance

1. Add up all the capacitance in the circuit, **allowing for the worst case tolerance on all the capacitive components.**

2. Enter the capacitive curves at the value obtained above and determine the maximum permissible voltage for the gas group concerned.

3. The actual allowed voltage will be 2/3 of this value.

4. Remember that the voltage obtained will be the maximum voltage including tolerance.

To determine maximum capacitance for a given voltage

1. Determine maximum voltage including tolerance. This will normally be the certified maximum output voltage of the associated apparatus, unless the intrinsically safe circuit under consideration includes any voltage increasing components such as transformers or integrated circuits with voltage changing elements. If the circuit does contain such elements, then use the highest voltage (again including any tolerance) for this procedure.

2. Enter the capacitive curves at 1.5 times the voltage obtained in 1, and determine the maximum permissible capacitance for the gas group concerned.

3. The capacitive value obtained will be the maximum permitted capacitance including tolerance. Remember, this value will

have to be sufficient for both the intended circuit and cable parameters of the system. [1]

As will be seen later in the chapter, capacitive stored energy effects may be reduced by protecting a capacitor with a series resistor, so if the total capacitance is too great, all is not lost. However, there are no curves available to determine the effect of a circuit containing some straight capacitors and some resistance protected capacitors, so ignition testing using the spark test apparatus will be necessary if the total capacitance exceeds the value from the curves.

For inductance checking, proceed in a similar way to that described above, but apply the factor of safety of 1.5 to the current. Note that at circuit voltage below 24 V the permitted inductance can be increased for currents below 200 mA. (See Appendix 1.)

Preliminary Checks for Temperature Classification

It is well worth taking advantage of the small components and low wattage surface temperature clause in EN 50 020. This is described in full in Chapter 6 and Table 6.1. [*]

Compliance with these requirements will enable the circuit to be assessed for surface temperature without the need (by the certification body [nominated body]) to embark on expensive temperature testing.

If the intended design conforms to the temperature requirements, and meets the values determined from the various ignition curves, and is intended to operate from a proprietary interface, then no further electrical assessment is needed and, apart from mechanical

---

* Remember that the temperatures under consideration relate to all components in the design. The fact that components may be within a case or housing does not alter the position, since the enclosure is neither gas tight nor 'explosionproof'.

considerations, the circuit is ready for an application for certification. [*]

Creepage and Clearance Distances

Consider the circuit shown in Figure 13.1.

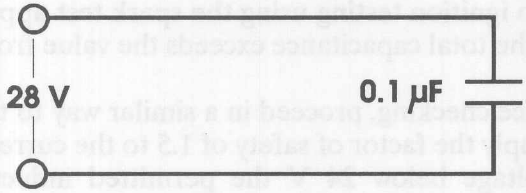

Figure 13.1 *Consideration of Creepage and Clearance Distances*

Reference to the capacitive curves will show that the capacitive level is too great for group IIC. The effect of the stored capacitive energy can be reduced by the inclusion of a series resistor as shown in Figure 13.2.

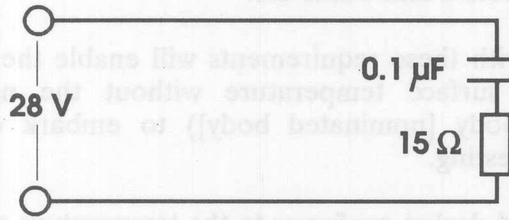

Figure 13.2 *Partial Suppression of Capacitive Effect by the use of a Series Resistor*

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* This desirably simple state of affairs is rare! If your circuit does comply, then it may be worth checking whether certification is really necessary and that the simple apparatus rules which obviate the need for certification are not applicable.

Now consider the actual layout of these components as shown in Figure 13.3. The solder side of the printed circuit board is shown, and it can be seen that the track from the bottom of the resistor passes very close to the track connecting the resistor to the capacitor.

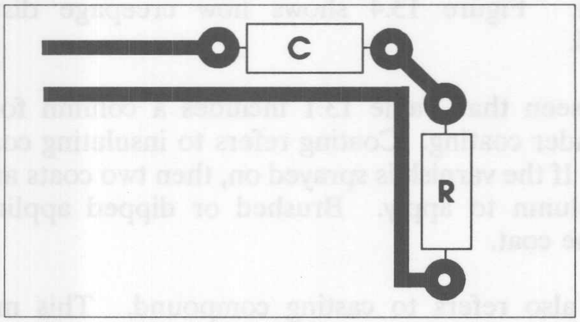

Figure 13.3 *Layout of Circuit shown in Figure 13.2 showing how the Resistor may be bypassed by other Tracks*

The track is so close to the resistor that it could, if it touched, have the effect of shorting out the resistor completely, thus negating its effect of limiting the capacitive discharge.

How far away does the track need to be?

Table 13.1 shows the creepage and clearance distances which are considered infallible at various voltages. If the distance meets that shown in the table, then shorts between the two conducting parts will not be considered.

If the distance is less then that shown, but exceeds 1/3 the value shown, then a short circuit will be considered, but counted as one fault. If the distance is less than 1/3 of the value shown, then a short circuit will be considered *without counting it as a countable fault*.

Clearance distances are the shortest distance in air between two conductive parts. [*]

Creepage distance is the shortest distance between two points along the surface of an insulator. Creepage distance can be increased by the careful use of insulating barriers - hills and valleys - between the two points. Figure 13.4 shows how creepage distances are determined.

It will be seen that Table 13.1 includes a column for creepage distance under coating. Coating refers to insulating coatings such as varnish. If the varnish is sprayed on, then two coats are required for this column to apply. Brushed or dipped application only requires one coat.

The table also refers to casting compound. This may be any suitable insulating compound which

- □ has a temperature rating, specified by the manufacturer of the compound which is at least equal to the maximum temperature achieved by any component under encapsulated conditions.
- □ has, at its free surface, a CTI [2] value of at least that specified in the table if any bare or conductive parts protrude from the compound.
- □ if the surface of the compound is exposed - forming part of the apparatus enclosure - it must be a hard compound, a sample of which has been tested and found to conform to the requirements of various mechanical tests including an impact test of 2 J. [3]

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* It should be noted that clearance is often defined as the *straight line* air distance between two points, such that if the two points under consideration cannot 'see' each other then clearance does not apply. The definition for clearance in intrinsic safety, however, allows for clearance to be around an obstacle.

Voltage (peak value) (V)		10	30	60	90	190	375	550	750	1000	1300	1575
Clearance (mm)		1.5	2	3	4	5	6	7	8	10	14	16
Separation distances through casting compound (mm)		0.5	0.7	1	1.3	1.7	2	2.4	2.7	3.3	4.6	5.3
Separation distances through solid insulation (mm)		0.5	0.5	0.5	0.7	0.8	1	1.2	1.4	1.7	2.3	2.7
Creepage distance in air (mm)		1.5	2	3	4	8	10	15	18	25	36	49
Creepage distance under coating (mm)		0.5	0.7	1	1.3	2.6	3.3	5	6	8.3	12	13.3
Comparative tracking index	ia		100	100	100	175	175	275	275	275	275	275
	ib		100	100	100	175	175	175	175	175	175	175

Note: At voltages of 10 V or less, CTI does not need to be specified.

Table 13.1 *Creepage and Clearance Distances*

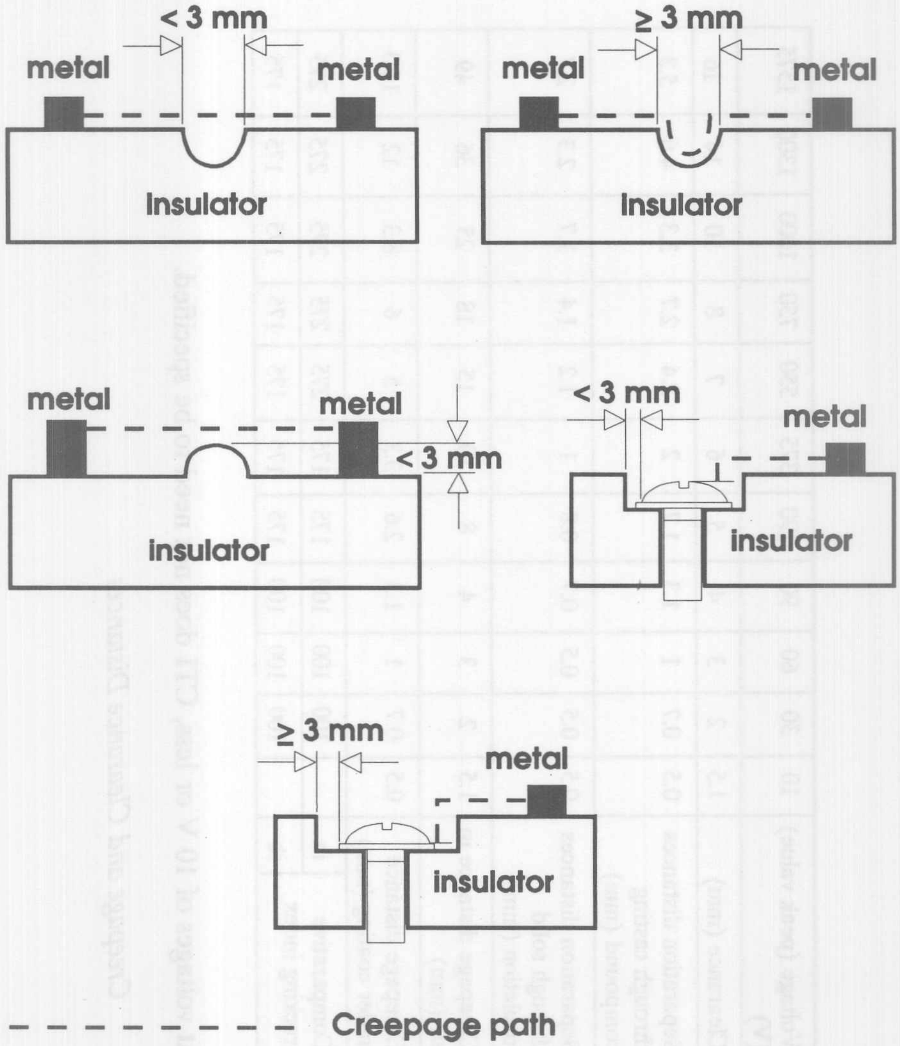

Figure 13.4 *Determination of Creepage Distances along Surfaces in Air*

- □ must adhere to all conductive parts, components and substrates except where they are totally enclosed by the compound.
- □ must be specified by its generic name and type designation given by the manufacturer.

If the compound is to be used to determine the necessary segregation between an encapsulated part and a conductor external to - but touching the surface of - the compound, then ½ the value shown in line 3 of the table will apply, subject to a minimum of 1 mm.

It should be clearly understood that creepage and clearance distances only apply where failure (short circuit) between two conducting parts could give rise to an unsafe (non-intrinsically safe) condition.

It should also be appreciated that the actual housing of many components is unspecified and undetermined. Thus, for example, exactly where, within a wire wound resistor, the resistive wire is situated, will almost certainly not be defined. Thus the component case cannot normally be used to achieve insulation requirements.

If it is essential to have live conductors in close proximity to components, for example if a printed circuit track goes under a component, consider oversleeving the component with an insulating sleeve. Insulation distances will need to comply with the table, but a 0.3 mm radial thickness will suffice in most cases.

Using Infallible Components

As shown in Chapter 5, it is often convenient to use infallible components or assemblies of components to achieve voltage or

current limiting. The most common infallible components are transformers and current limiting resistors. Zener diodes for determining maximum voltage are not infallible components and need to be treated to fault analysis. This is described later in the chapter.

Infallible Current Limiting Resistors

Resistors may be used to achieve infallible current limiting if they are film type or wire wound types, or printed resistors as used in hybrid and similar circuits covered by a coating or encapsulated. The resistor must be rated to withstand at least 1.5 times the maximum voltage and 1.5 times the maximum power which can arise in normal and in fault conditions.

Such resistors are deemed only to be able to fail to an open circuit condition and are thus infallible for current limiting purposes. Their failure to open circuit may, however, be considered as a countable fault for other purposes.

Infallible Mains Transformers

The term infallible, applied to mains transformers, means that faults giving rise to a short between a winding supplying an intrinsically safe circuit and any other winding, need not be considered. Short circuits within a winding and open circuits of windings are to be considered.

Mains transformers require a fuse or circuit breaker to determine the maximum current to which the primary winding may be subjected. Electricity supply systems not exceeding 250 V ac are deemed to be capable of supplying 1500 A ac, and thus fuses need to be able to interrupt prospective currents of this level. [4] The fusing current is deemed to be 1.7 times the fuse rating. If the fuse

needs to be installed within the hazardous area, and is not itself protected by another method of protection such as being within a flameproof - Ex d - enclosure, then it must be encapsulated in such a way that explosive atmospheres are excluded. The method for achieving this is described later in this chapter. [*]

In essence, there are two types of infallible mains transformer construction:

- (type 1)
  different windings on different legs of the core or, if on the same leg then side by side (as opposed to one over the other).

- (type 2)
  different windings wound one over another, with either solid insulation or an earthed copper foil or equivalent wire winding between the windings.

Where an earthed screen is used for a type 2 construction, then the minimum thickness of the screen must comply with Table 13.2.

Rating of fuse (A)	0.1	0.5	1	2	3	5
Thickness of foil screen (mm)	0.05	0.05	0.075	0.15	0.25	0.3
Diameter of wire used for screen (mm)	0.2	0.45	0.63	0.9	1.12	1.4

Table 13.2 *Minimum Thickness of Transformer Screen in relation to Transformer Fuse*

Foil screens must be provided with two mechanically separate leads

* Encapsulation for the purposes of excluding a potentially flammable atmosphere is quite different to encapsulation for insulation requirements.

to the earth connection. Both leads must be rated to carry the maximum continuous current which could flow before the fuse or circuit breaker operates. (1.7 x fuse rating.)

Wire screens must consist of at least two electrically independent layers of wire, each of which is provided with an earth connection rated as above. The insulation between layers must be capable of withstanding a 500 V insulation test for one minute without breakdown.

Infallible Transformers Other Than Mains Transformers

Transformers used for coupling of different intrinsically safe circuits or for inverter power supplies will be infallible in respect of a short between one winding and another if they comply with the construction technique outlined above.

Voltage Clamps

The most common voltage clamp used for intrinsically safe purposes is the zener diode. Since the zener diode on its own is not deemed infallible for voltage limiting - that is to say open circuit failure must be considered - an infallible assembly may be constructed with two parallel paths of shunting zener diodes. [5] The constructional details for printed circuit track and general wiring are described later in the chapter.

Typical applications for such safety shunts are:

- general circuit voltage clamping to comply with minimum ignition curve requirements

- using zener diodes to clamp the voltage within a circuit to allow capacitive energy to be assessed at a voltage other

(lower) than the interface output voltage

using diodes to limit the possible discharge from a coil (inductor) or piezoelectric device

Series Current Limiting Semiconductors

Series current limiting using semiconductor devices is not permitted except

a) in 'ib' circuits

b) in the case of three series blocking diodes for 'ia' or 'ib'.

The series limiting components are not deemed infallible, and assessment needs to consider one or two failures as applicable. The series limiting component(s) must be adequately rated with the factor of safety of 1.5.

Connections and Wiring

Printed circuit board copper tracks may be considered as not subject to open circuit fault providing

- □ there are two tracks of at least 1 mm width in parallel or
- □ a single track has at least 2 mm width or a width of 1% of its length, whichever is greater, and
- □ each track is formed from copper cladding having a nominal thickness of at least 35μm.

Wiring is not deemed subject to open circuit fault if there ..

- ☐ are two wires are in parallel, or

- ☐ is a single wire which is of at least 0.5 mm diameter with an unsupported length of less than 50 mm or which is otherwise mechanically secured adjacent to its point of connection, or

- ☐ is a single wire of stranded or flexible ribbon type construction with a cross sectional area of at least 0.125 mm^2 (0.4 mm diameter), where the wire is not flexed in service and is either less than 50 mm long or secured adjacent to its point of connection.

Connections are not deemed subject to open circuit fault if there ..

- ☐ are two connections in parallel, or

- ☐ is a single connection via a printed circuit board where the wire passes through the board and is either bent over before soldering or is machine soldered or has a crimped connection or is brazed or welded, or

- ☐ is a single screwed and bolted connection which is protected against self loosening [6]

Temperature Classification for Copper Wiring

The Table 13.3 indicates the size and current carrying capacity relationship for various temperature classifications of copper wire. Printed circuit board wiring is assessed for temperature in accordance with Table 13.4.

Nominal Diameter (mm)	Nominal Cross-sectional Area (mm^2)	Maximum permissible current for temperature classification (A rms ac or dc)		
		T1 - T4 and Group I	T5	T6
0.035	0.000962	0.53	0.48	0.43
0.05	0.00196	1.04	0.93	0.84
0.1	0.00785	2.1	1.9	1.7
0.2	0.0314	3.7	3.3	3.0
0.35	0.0962	6.4	5.6	5.0
0.5	0.196	7.7	6.9	6.7

- For stranded conductors the cross-sectional area is taken as the total area of all strands of the conductor.
- Where the power does not exceed 1.3 watts, the wiring can be awarded T4 and is acceptable for group I even if not complying with the above values.

Table 13.3 *Temperature Classification for Copper Wiring*

Maximum track width (mm)	Maximum permissible current for temperature classification (A, ac rms or dc)		
	T1 to T4 and Group I	T5	T6
0.15	1.2	1.0	0.9
0.2	1.8	1.45	1.3
0.3	2.8	2.25	1.95
0.4	3.6	2.9	2.5
0.5	4.4	3.5	3.0
0.7	5.7	4.6	4.1
1.0	7.5	6.05	5.4
1.5	9.8	8.1	6.9
2.0	12.0	9.7	8.4
2.5	13.5	11.5	9.6
3.0	16.1	13.1	11.5
4.0	19.5	16.1	14.3
5.0	22.7	18.9	16.6
6.0	25.8	21.8	18.9

- Values apply to printed circuit boards of 1.6 mm or thicker with single layer copper of 35μm thickness.
- If board thickness is >0.5 mm <1.6 mm divide maximum current by 1.2

Table 13.4 *Temperature Classification for Printed Circuit Board Wiring*

Requirements for Terminals and Plugs and Sockets used for the External Connection to Intrinsically Safe Circuits (apparatus)

If failure between terminals could lead to an unsafe condition, then the requirements for creepage and clearance set down in Table 13.1

must be met. In addition, terminals for intrinsically safe circuits shall be separated from terminals of non-intrinsically safe circuits by either ..

a) separation of the intrinsically safe and non-intrinsically safe terminals by at least 50 mm clearance distance, and by physical arrangement such that if a wire becomes dislodged, contact between circuits is not likely.

or ..

b) by arranging the intrinsically safe and non-intrinsically safe terminals in separate enclosures (compartments) or by the use of an insulating partition or earthed metal screen between the terminals with a common cover and where:

   the partition providing separation extends to within 1.5 mm of the enclosure walls or provides a distance of at least 50 mm between terminals when measured in any direction around the partition

   if a metal partition is used, then it must have a thickness of at least 0.45 mm or be capable of withstanding a specified 30 N test. In either case, the partition must have sufficient current carrying capacity to prevent burn-through or loss of earth connection

   if a non-metallic insulating partition, then it must have sufficient thickness and be so supported that it cannot deform in a way which would defeat its purpose. It shall be at least 0.9 mm thick or be subjected to a specified 30 N test.

Additionally, the clearance between bare conducting parts of terminals or external conductors connected to the terminals used for separate intrinsically safe circuits should be at least 6 mm.

Plugs and sockets used for the external connection of intrinsically

safe circuits must be non-interchangeable with those used for non-intrinsically safe circuits.

Use of Encapsulation

Encapsulation has two main uses within intrinsic safety design, and it is important that they are not confused.

- □ Encapsulation may be used for insulating purposes as already covered in the table on creepage and clearance distances and explained in the text.
- □ Encapsulation may be used as a means of excluding a potentially flammable atmosphere from a part of a circuit such as a piezoelectric device [7] or a fuse.

This latter use covers both prevention of the hazardous atmosphere reaching parts of circuits which are not intrinsically safe and reduction of surface temperatures which would otherwise lead to ignition capability by exceeding the desired temperature class. The encapsulation must meet the general requirements specified earlier in this chapter.

Protecting Excess Capacitance

The general concept that capacitive levels which were in excess of that permitted by the minimum ignition curves could be protected was explained earlier in the chapter. The first edition of EN 50 020 included curves for capacitance and capacitance together with series resistance. These curves are reproduced at Figure 13.5 since the concept of such protection is still valid. They should, however, only be used as a rough guide, since they do not show the effect of a mixture of unprotected capacitance together with protected capacitance, [8] and the capacitive curves have been revised at

edition 2 of EN 50 020. Designers certifying to the second edition should use the curves from that standard. (See Appendix 1)

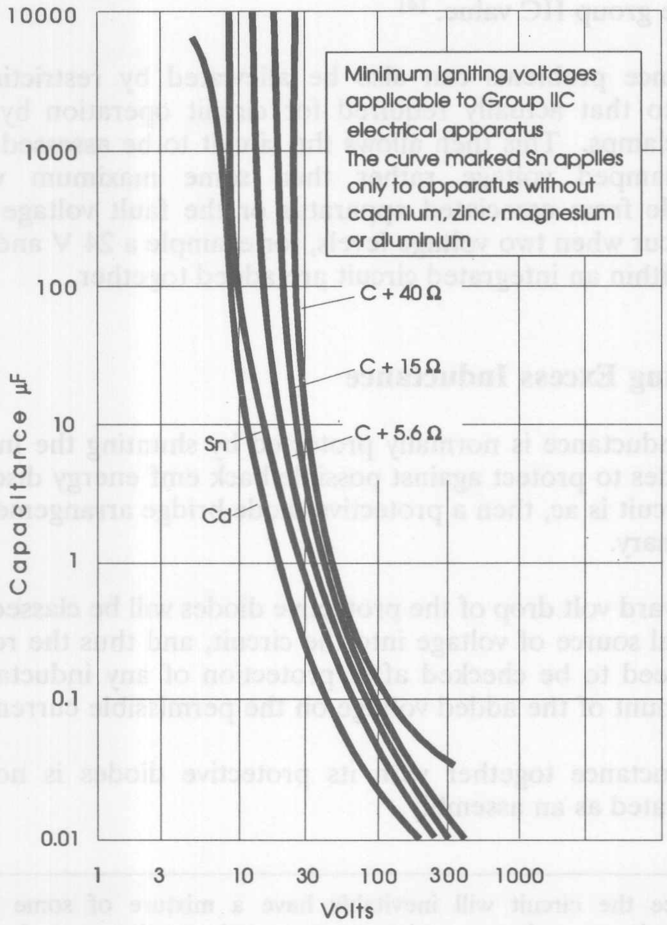

Figure 13.5 *Curves showing Minimum Ignition Energy from Capacitors Protected with Series Resistance*

For guidance only. For design purposes use curves in EN 50 020 Edition 1.

It should be noted that the curves only give values for gas group IIC. The permitted values for group IIB will be about 3 times the group IIC values, and the permitted values for group IIA about 8 times the group IIC value. [*]

Capacitance problems can also be alleviated by restricting the voltage to that actually required for circuit operation by zener voltage clamps. This then allows the circuit to be assessed at the zener clamped voltage rather than some maximum voltage obtainable from associated apparatus or the fault voltage which could occur when two voltage levels, for example a 24 V and a 5 V supply within an integrated circuit are added together.

Protecting Excess Inductance

Excess inductance is normally protected by shunting the inductor with diodes to protect against possible back emf energy discharge. If the circuit is ac, then a protective diode bridge arrangement will be necessary.

The forward volt drop of the protective diodes will be classed as an additional source of voltage into the circuit, and thus the resistive curves need to be checked after protection of any inductance to take account of the added voltage on the permissible current.

The inductance together with its protective diodes is normally encapsulated as an assembly.

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* Since the circuit will inevitably have a mixture of some straight capacitance and some resistance protected capacitance, and will thus need spark test assessment, these approximate values should be sufficient to serve as a guide. In practice they will probably be somewhat pessimistic. It is, however, worth remembering that the effect of the resistor is not to reduce the capacitive energy to zero. Thus even protected capacitance will still contribute to the overall capacitive energy stored.

Mechanical Considerations of Intrinsic Safety Design

As has been mentioned already, there are situations, such as protective partitions for terminals of differing circuits, where mechanical requirements such as impact tests do form part of the considerations. However, such special situations apart, the mechanical requirements for intrinsic safety are minimal, and probably no more than would be necessary for normal functional protection purposes.

As far as ingress protection is concerned, IP20 is the normal minimum requirement, although there are some exceptions to this. Group I apparatus requires IP54. In many instances, IP54 will be required even for surface industry for operational reasons.

Mechanical impact tests - 7 J test - required by the general part of EN 50 014 do not normally apply to intrinsic safety, except where piezoelectric devices are included in the circuit.

Piezoelectric devices will be subjected to the impact tests with any guard etc. in place, and the maximum energy produced evaluated from determining the capacitance of the device and measuring the maximum voltage produced under impact test conditions.

The limits for stored energy on piezoelectric devices tested as above are:

1500	μJ for group I apparatus
950	μJ for group IIA apparatus
250	μJ for group IIB apparatus
50	μJ for group IIC apparatus

Portable Apparatus

The mechanical consideration for portable apparatus is a 1 m drop test. Again, the acceptance criteria is simply that the protection concept is not lost as a result of the test.

The main electrical considerations for portable apparatus concern the presence and use of batteries within the apparatus and this subject is covered separately since it can apply to apparatus other than portable apparatus.

Batteries and Cells

The first point to note about cells and batteries is that certain types can explode when short circuited or subjected to reverse charging. Care needs to be taken to ensure that such an occurrence does not affect intrinsic safety. An attestation from the battery manufacturer on the behaviour of batteries may be necessary.

Secondly, cells and batteries shall be of such construction that either the electrolyte cannot spill, or be enclosed to prevent any spillage causing damage to components upon which intrinsic safety depends. Normally, cells and batteries which are sold as sealed ('gas tight' or 'valve regulated') will be acceptable. Alternatively, encapsulation of the cell or battery may be possible (subject to type tests for leakage of electrolyte in the encapsulated condition).

Cells and Batteries - Electrical Considerations

For intrinsic safety evaluation purposes, cells and batteries are considered in terms of their maximum open circuit voltage from an 'as new' battery or a battery fully charged. Certain cells and battery types have defined voltages as shown in Table 13.5. Otherwise samples will require testing to determine these values.

Clearly, having defined the applicable voltage, the maximum current into the intrinsically safe circuit under short circuit conditions needs assessment. This normally means that some current limiting device will be required which is electrically directly connected to the battery terminals. As stated earlier in the chapter, series semiconductor current limiting is only permitted for 'ib' apparatus. Resistance current limiting is acceptable for either 'ia' or 'ib' and is achieved as considered elsewhere in the book.

IEC Type	Cell Type	Peak open circuit voltage for spark hazard (V)	Nominal voltage for component surface temperature assessment (V)
K	Nickel-cadmium	1.5	1.3
	Lead-acid (dry)	2.35	2.2
	Lead-acid (wet)	2.67	2.2
L	Alkaline-manganese	1.65	1.5
M	Mercury-zinc	1.37	1.35
N	Mercury-manganese Dioxide-zinc	1.6	1.4
S	Silver-zinc	1.63	1.55
A	Zinc-air	1.55	1.4
C	Lithium-manganese dioxide	3.7	3.0
	Zinc-manganese dioxide (zinc-carbon Leclanche)	1.725	1.5
	Nickel-hydride	1.6	1.3

Table 13.5 *Cell Voltages*

Cells and Batteries - Mechanical Considerations

The mechanical considerations depend upon the intended use and replacement of the cell or battery as indicated in Table 13.6.

Requirement for	Cells and batteries used in associated apparatus	Cells and batteries for use in hazardous area intrinsically safe apparatus where the battery may be replaced whilst in the hazardous area	Cells and batteries for use in hazardous area intrinsically safe circuits, but which will not be replaced whilst in the hazardous area
Current limiting device	Need not be in same enclosure (housing) as battery	Must be an integral unit with the battery so that battery and current limiting device are removed and replaced together	No special requirement if battery compartment complies with below. Otherwise protect as for hazardous area replaceable battery.
Battery housing	Constructed such that installation and replacement of battery will not adversely affect intrinsic safety	If current limiting is required, must be encapsulated or otherwise enclosed so that only intrinsically safe terminals are exposed	If current limiting required, house battery in compartment which complies with requirements for special fasteners and: □ must not disconnect battery when subject to drop test if portable apparatus □ connection arrangement such that it cannot be incorrectly connected to the detriment of intrinsic safety □ Apparatus must bear label 'DO NOT OPEN BATTERY ENCLOSURE IN A POTENTIALLY EXPLOSIVE ATMOSPHERE'

Table 13.6 *Battery Requirements*

Marking Requirements

Certified intrinsically safe apparatus will require a certification label. It is worthwhile giving some thought as to how and where this label will be affixed at an early stage in the design.

Marking is required to be *legible and durable taking possible chemical corrosion into account*. This wording, from EN 50 014, is somewhat open to interpretation by the certifying officer. However, adhesive labels which can readily be removed by peeling them back after flicking up the corner with a finger nail are unlikely to be allowed.

It is now possible to obtain self-adhesive material which is made from 'ultra-destructible vinyl', and which, if removal is attempted, will break up, only allowing very small parts of the label to be peeled off. This type of material has been accepted by various nominated bodies and is a good solution where adhesive labels are required.

Alternatively, adhesive labels may be fixed into a recess so that removal is significantly harder.

Engraving, including engraving on a separate plate which is then fixed with rivets, is perfectly acceptable. (Fixing with screws may not be acceptable because of the possibility of easy removal.)

It is worth giving some thought to having separate labels for the certification data and other manufacturer's data so that uncertified information can subsequently be altered without the need to obtain a variation to the certificate.

Terminal identification, and identification of plugs and sockets etc. is often achieved by using the colour light blue to indicate intrinsic safety.

SUMMARY

- □ The first stage in intrinsic safety design is to check against the resistive curves and then check total C and L against the capacitive and inductive curves. Then check for T-Class using 1.3 watts rule.

  Simplify design if possible to achieve IS criteria from above.

- □ Apply FOS 1.5 to voltage for capacitive curves and to current for inductive curves.

- □ Check for compliance with creepage and clearance requirements when using current limiting resistors or other components upon which intrinsic safety depends.

- □ Use infallible components to make assessment easier.

- □ Only use semiconductor current limiting in 'ib' circuits.

- □ Take extra care if circuit contains cells or batteries.

- □ Careful use of encapsulation can alleviate problem areas.

NOTES AND REFERENCES

1. See Chapter 12 for information on cable parameters, and Chapter 9 for system considerations.

2. CTI: Comparative Tracking Index. (See IEC-112, BS 5901 etc.)

   The comparative tracking index of an insulating material indicates the ease with which the surface of the material may be contaminated with carbon deposits resulting from the conduction of electricity under damp conditions. If the CTI is low, then a permanent track may be formed after drying if there has been conduction whilst the surface is wet. Thus the higher the CTI value the better.

3. 20 J for some group I apparatus.

4. The prospective current is not the fuse rated current. The prospective current capacity of the fuse determines the *maximum* current the fuse will break.

5. Diodes, as well as zener diodes may be used to form an infallible shunt assembly in the same way.

6. Such a connection may be achieved by using a terminal which meets the requirements of increased safety; Ex e.

7. The piezoelectric device will normally need to be encapsulated with voltage limiting zener diodes across its terminations.

8. Circuits which contain both unprotected capacitance and resistance protected capacitance (or a number of capacitors protected by different value resistors) cannot be assessed from the curves and an equivalent circuit will need to be tested using the spark test apparatus. This situation has always been true, but many people mis-understood the use of the curves for resistance protected capacitance and assumed that the

stored energy effect of a resistance protected capacitor was zero.

CHAPTER 14

Installation and Application of Intrinsically Safe Apparatus and Systems

This chapter includes information on

General installation criteria and diagram
Special situations:
    installation of associated apparatus in the hazardous area
    installations which cannot meet 500 V insulation
Zone 0 installations
Lightning protection
Use of multiplexers
Line monitoring and earth fault detection
Avoiding disabling earth faults of dual channel barrier circuits

Installation and Application of Intrinsically Safe Apparatus and Systems

The installation and application of intrinsic safety impinges on a number of topics such as wiring, the use of simple apparatus, and system considerations all of which are the subject of separate chapters. Thus it will be necessary for the reader to refer to those topics in conjunction with the information in this chapter.

As has already been stated, intrinsic safety is a system concept. Thus the installation of intrinsically safe apparatus and associated apparatus needs to be carried out in such a way that the intrinsic safety of the system is not jeopardised by invasion from, or the effects of, other (non-intrinsically safe) circuits.

General Installation Requirements

The general form of installation is depicted in Figure 14.1

The following points should always be considered.

Marking of Intrinsically Safe Installations

Intrinsically safe installations should always be identified as such to minimise the danger of intrinsically safe circuits being degraded by future modifications to plant or site.

The way in which identification is achieved is not specified, but if identification is by means of a colour it should be light blue. Thus it is common practice to use blue sheathed cable, junction boxes painted blue and blue terminals within junction boxes containing intrinsically safe circuits. It should, however, be understood that it is not mandatory to use blue terminals etc.

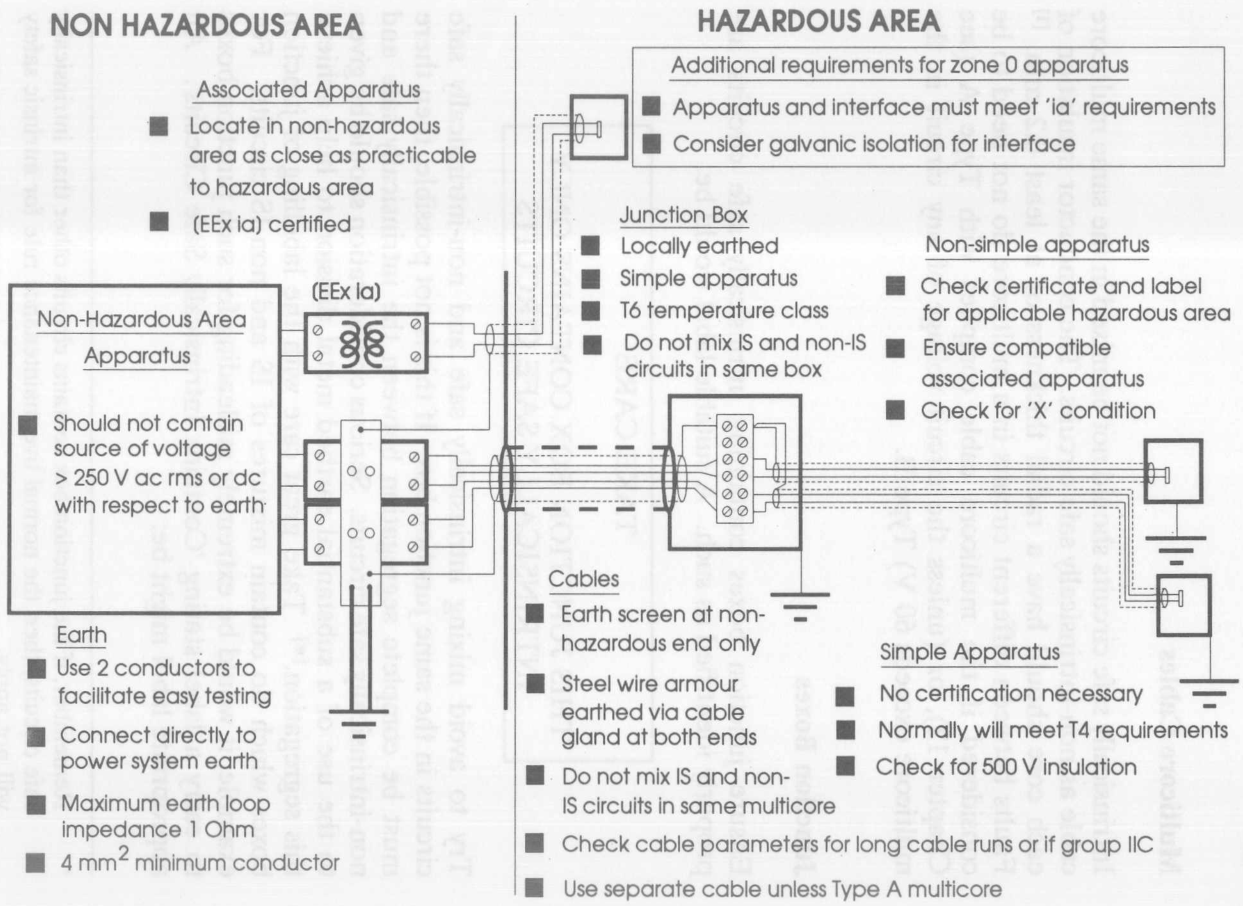

Figure 14.1 *General Installation Requirements for Intrinsic Safety*

Multicore Cables

Intrinsically safe circuits should not be mixed in the same multicore cable as non-intrinsically safe circuits. The conductor insulation of each core should have a radial thickness of at least 0.2 mm. [1] Faults between different circuits in a multicore do not need to be considered if the multicore cable complies with Type A (see Chapter 12), or (unless the circuit voltage of any circuit in the multicore exceeds 60 V) Type B.

Junction Boxes

Ensure junction boxes containing intrinsically safe circuits are properly identified as such. A suitable label would be:

TAKE CARE THIS JUNCTION BOX CONTAINS ONLY INTRINSICALLY SAFE CIRCUITS

Try to avoid mixing intrinsically safe and non-intrinsically safe circuits in the same junction box. If this is not possible, then there must be complete segregation between the intrinsically safe and non-intrinsically safe circuits. Serious consideration should be given to the use of a substantial earthed metal division to help achieve this segregation.[*] Take great care with the labelling of junction boxes which do contain mixtures of IS and non-IS circuits. For example, it would be extremely misleading for such junction boxes to carry a label stating 'Contains Intrinsically Safe Circuits'. An appropriate label might be:

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* Remember, if the junction box contains circuits other than intrinsically safe circuits, then the normal live maintenance rule for intrinsic safety will not apply.

TAKE EXTREME CARE THIS JUNCTION BOX CONTAINS BOTH INTRINSICALLY SAFE AND NON INTRINSICALLY SAFE CIRCUITS NORMAL INTRINSIC SAFETY INSPECTION RULES DO NOT APPLY

Insulation Test

Remember that the entire installation from the associated apparatus onwards must be able to withstand a 500 V insulation test to earth or frame of apparatus. If the apparatus is certified, this requirement will almost certainly be automatically met by virtue of complying with the certification requirements. However, some certified apparatus, for example conductivity probes and similar equipment may not comply. This may be indicated by an 'X' condition (see Chapter 3) in the certificate.

It is also important to remember that simple apparatus may not automatically meet the 500 V insulation requirements. Such items as thin film strain gauges may be especially worthy of attention.

If the 500 V test cannot be achieved, then the normal solution is to introduce galvanic isolation into the system loop. This may be achieved either at the associated apparatus or via some interposing apparatus. See Figure 10.7 and 10.8 in Chapter 10.

An alternative solution to this problem is to take steps to ensure that there is no potential difference between earth in the hazardous area and the earth point of the associated apparatus. The concept is shown in Figure 14.2.

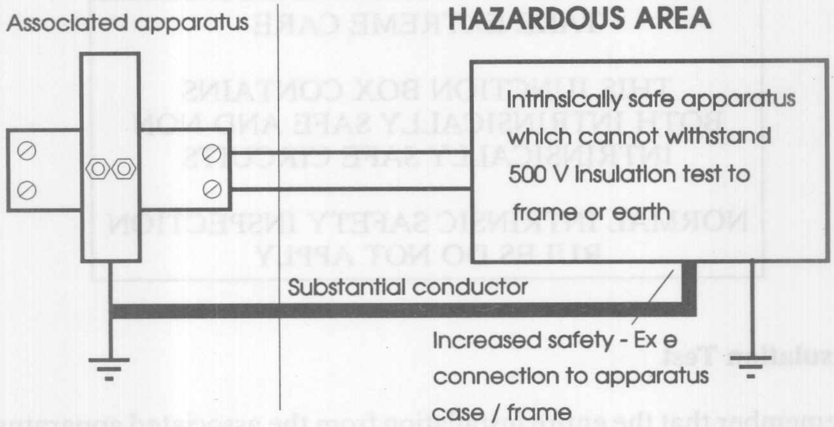

Figure 14.2 *Alternative Solution for Installations which cannot meet 500 V Test Requirement*

It should be stressed that, although this approach was used quite widely before galvanic isolation techniques were commonly available, it is no longer a preferred solution. If it is used, then care should be taken to ensure that the equipotential bonding arrangement really will function correctly.

Amongst other considerations, the connections of the bonding conductor to the hazardous area apparatus should be such that it cannot come loose, giving rise to a potentially sparking situation. Thus this connection should be a connection which meets increased safety requirements (except for IP rating). The distance between the intrinsically safe apparatus in the hazardous area and the associated apparatus should normally be no longer than 100 m.

Situations where the Associated Apparatus Cannot be Located in the Non-hazardous Area

Occasionally, there are situations where the associated apparatus needs to be located in the hazardous area. This should normally be avoided, but where there is no alternative, then it must be understood that the associated apparatus itself needs to be protected in some way, since it is only the output of the associated apparatus which is intrinsically safe.

There are a number of possible solutions to this problem, of which the most common is to locate the associated apparatus within a flameproof enclosure. (Figure 14.3)

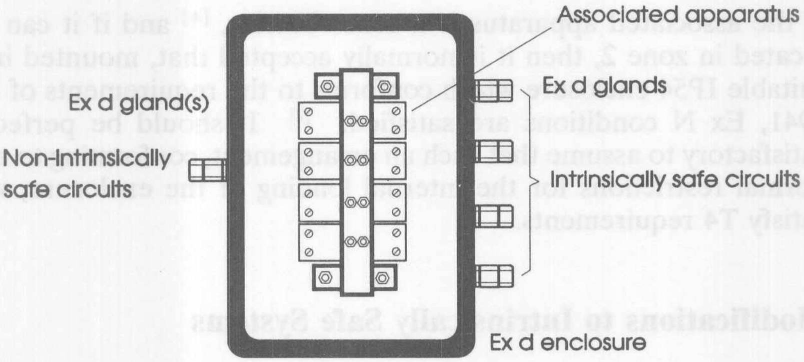

Figure 14.3 *Using an Ex d Enclosure to locate Associated Apparatus in the Hazardous Area*

Several manufacturers of flameproof enclosures have certificates which permit the installation of zener barriers and other associated apparatus without the need for additional certification.

Clearly, the enclosure should bear an additional suitable label to warn that it contains intrinsically safe circuits. This label should not

be fixed in such a way that the flameproof integrity of the enclosure is jeopardised. Any blind rivet holes etc. should be drilled by the enclosure manufacturer / certificate holder. Remember that for the enclosure's flameproof integrity to be maintained, the correct *flameproof cable glands will need to be used for all the cable entries* - regardless of whether the cables themselves contain circuits which are intrinsically safe or otherwise. Since the temperature classification of flameproof protection only needs to consider the external surfaces of the flameproof enclosure, such an arrangement may safely assume T6 if the associated apparatus comprises zener barriers. The same is probably true of most galvanic isolation interfaces, but because some of these units can dissipate significant heat, it would probably be prudent to assume T4 if galvanic isolators are used for the associated apparatus.

If the associated apparatus is a zener barrier, [*] and if it can be located in zone 2, then it is normally accepted that, mounted in a suitable IP54 enclosure which conforms to the requirements of BS 6941, Ex N conditions are satisfied. [2] It should be perfectly satisfactory to assume that such an arrangement, conforming to any normal restrictions for the internal loading of the enclosure, will satisfy T4 requirements.

Modifications to Intrinsically Safe Systems

It should be clear that changes to any item within an intrinsically safe system loop may result in changing the intrinsic safety properties of the whole loop. Thus, before any change - other than the introduction of additional items of simple apparatus [**] - is

* The specific restriction to zener barriers is because some galvanic isolation units contain internal relays etc. which are regarded as normally sparking components.

** Even simple apparatus may need consideration if it includes 'sources of stored energy with well defined parameters'. See Chapter 7.

contemplated, the effect of the modification on the whole circuit must be considered.

Sometimes, certified intrinsically safe apparatus is designed so that all the internal circuitry, possibly containing capacitive and inductive elements, is protected at the input terminals in such a way that it cannot have an additive effect to the system considerations. (Although it is not simple apparatus, it 'appears as simple apparatus' to the system.) Such an approach is commonly employed for such items as loop powered indicators so that they can, indeed, be added to a certified system loop at a later stage without affecting the intrinsic safety considerations of the system or invalidating an existing system certificate. The position is normally explained in the certificate by stating that the apparatus terminals conform to the requirements of clause [simple apparatus] in [applicable standard].

Apart for the specifications explained above, modifications should be restricted to replacing items of certified intrinsically safe apparatus with alternative items of certified apparatus which have safety parameters no less safe than the original item. This will mean that the values of U_i ($U_{max\ in}$), I_i ($I_{max\ in}$), C_i (C_{eq}), L_i (L_{eq}) etc. of the intended replacement item will need to be compared against values of the original item. Refer to Chapter 9 for more details.

Zone 0 Installations

Clearly, special care needs to be taken when intrinsically safe apparatus is to be installed in a zone 0 area. The first point to understand is that for zone 0, all the parts of the intrinsically safe system, including the associated apparatus, must meet 'ia' conditions. If any part of the system is 'ib', then the entire system is downgraded to 'ib'.

In practice, this will rarely produce a problem, since most certified intrinsically safe apparatus is designed and certified to 'ia'.

There is a minor difference between the CENELEC System standard (EN 50 039) and the UK Code of practice (BS 5345: Part 4: 1977) as regards the use of multicore cables for zone 0. The UK Code of practice indicates that:

> *'Where intrinsically safe systems or parts of systems are used in zone 0 interconnecting cables containing more than one intrinsically safe circuit should not be used in any part of the intrinsically safe system unless it can be shown that no combination of faults between the intrinsically safe circuits within the cable can lead to an unsafe condition.'*

In practice, such analysis is not always easy, and for many years this led to the practice of not installing circuits for zone 0 in multicore cables. The CENELEC System standard indicates, however, that faults between cores within a multicore do not need to be considered if the cable is a Type A cable, or (if no circuit has a peak voltage exceeding 60 V) a Type B cable. (See Chapter 12 for full definition and explanation of cable types.)

Since there is normally no difficulty in complying with the requirements for Type A cable, this is the simplest solution and obviates the need to consider faults between different circuits in a multicore. Even within the UK, it is now generally accepted that this approach is perfectly acceptable for zone 0 installations.

An alternative, though far less attractive solution, which can be adopted when Type A (or B) cables cannot be used, and where one or more circuits in a multicore cable are for zone 0 application, is to introduce a further interface unit at the end of the multicore cable for all circuits going to zone 0. The principle is shown in Figure 14.4.

This approach is only likely to be economic and practical in unusual circumstances, but there are occasions where it is worthwhile. Remember, however, that if the installation is expected to conform to the CENELEC standards, then faults between cores of cables

which are not Type A (or B if the relevant condition is met) will need to be considered for all zones anyway, so the solution will not be acceptable to European standards.

The interface unit should probably be of the galvanic isolating type and will need to be loop powered.

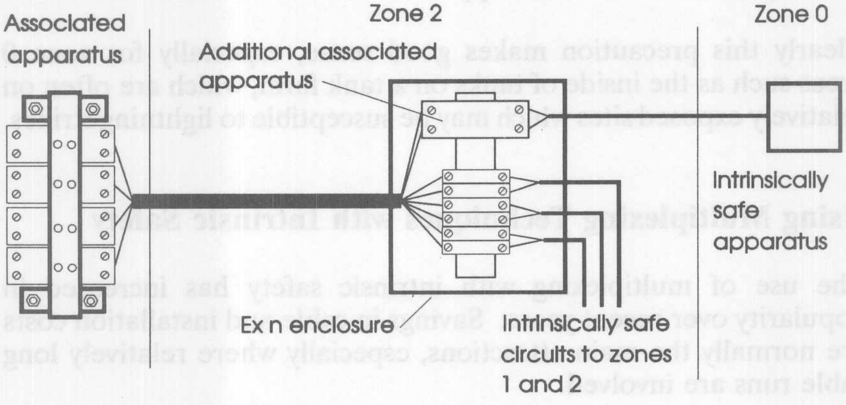

Figure 14.4 *Alternative solution for Zone 0 Circuits sharing a Multicore Cable which cannot be considered fault exempt*

Associated apparatus for zone 0 circuits must be [EEx ia] (or [Ex ia] if the system is only required to comply with national standards). There is now a clear preference for galvanic isolation to be used for zone 0, although zener barrier interfaces are still allowed providing the necessary earthing arrangements can be fully met.

Lightning Protection

The CENELEC installation standard (EN 50 154) recommends that where intrinsically safe circuits are installed in zone 0 areas outside buildings or above ground, lightning arrestors should be installed

between each non-earthed core of the cable and the plant earth (such as the metalwork of the tank which provokes the zone 0 area). The lightning arrestor should be installed as close as reasonably practicable to the zone 0 area (eg within 1 m of the zone 0 boundary). This action is intended to protect against lightning strikes inducing high voltages into the cable between the zone 0 circuitry and the associated apparatus in the non-hazardous area.

Clearly this precaution makes good sense, especially for zone 0 areas such as the inside of tanks on a tank farm, which are often on relatively exposed sites which may be susceptible to lightning strikes.

Using Multiplexing Techniques with Intrinsic Safety

The use of multiplexing with intrinsic safety has increased in popularity over recent years. Savings in cable and installation costs are normally the main attractions, especially where relatively long cable runs are involved.

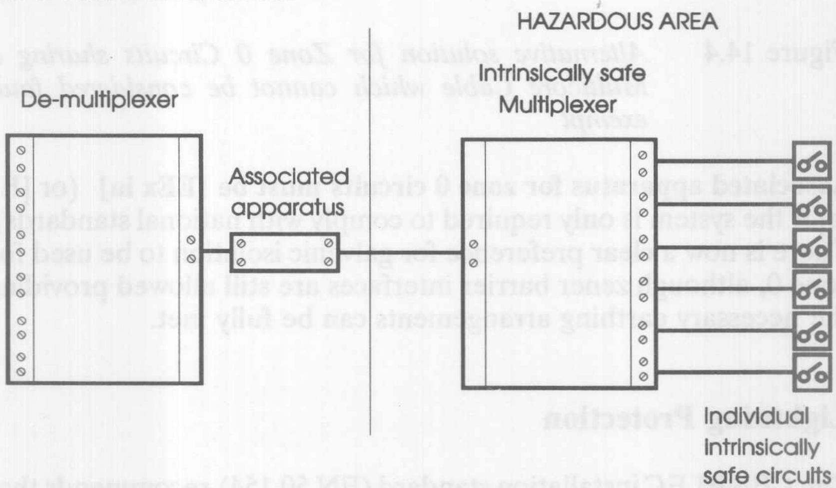

Figure 14.5 *Basic Intrinsically Safe Multiplexing System*

Multiplexing applications can also be extremely useful to allow additional circuits to be installed in an existing multicore which has no spare cores.

The early intrinsically safe multiplexers were solely for switch signals, and followed the general form shown in Figure 14.5.

The de-multiplexer is located on the non-hazardous area side of the associated apparatus, and thus does not enter the considerations for intrinsic safety. The multiplexer in the hazardous area is, of course, certified intrinsically safe apparatus.

The use of multiplexing techniques has now been extended to RTD's, apparatus such as thermocouples etc. giving a milli-volt output, and to 4-20 mA loop powered transmitters.

Although multiplexing can be extremely cost effective and useful, it is worth bearing in mind that the multiplexed signals may share a common mode failure condition. The vulnerable points are normally the interconnecting cable and the intrinsic safety interface unit (associated apparatus) which will be common to all the signals in the multiplexed arrangement. Furthermore, the MTBF of the multiplexing and de-multiplexing apparatus itself may need to be considered for highly critical process functions.

The possibility of a highway loop which duplicates the multiplexing apparatus and allows signal integrity even if the highway is broken overcomes these problems to some extent. The multiplexer manufacturer should be consulted to establish exactly what arrangements are possible.

General Information on Line Monitoring and Earth Fault Detection

It is often necessary or advisable to install the circuit in such a way that some line monitoring or earth fault detection is possible. The

simplest line monitoring normally comprises a resistor across the hazardous area apparatus (for example a switch) as shown in Figure 14.6.

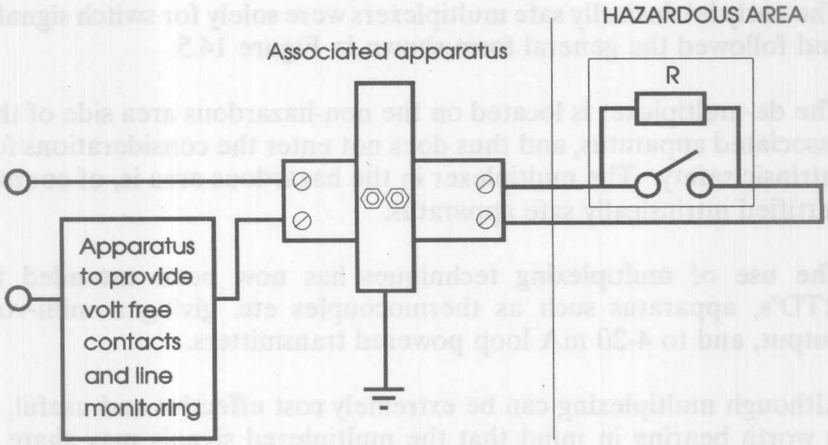

Figure 14.6 *Simple Line Monitoring of a Switch Circuit*

The resistor is regarded as simple apparatus and thus does not impinge on the intrinsic safety considerations of the circuit. Choice of a suitable value resistance will enable the distinction between switch closed (short circuit), switch open, and open circuit line faults to be differentiated.

Although some degree of earth fault monitoring may be obtained by simply comparing (on the non-hazardous area side of the associated apparatus) the current in the outgoing and return side of the loop, it is now more common to introduce some form of separate earth fault monitoring unit. These units are normally available from the manufacturer of the associated apparatus and are physically of a style which is compatible with the associated apparatus. Furthermore, it is normally possible for one earth fault detector to monitor several loops.

Using Zener Barrier Interfaces with Floating Circuits

If the circuits connected to the non-hazardous area side of the zener barrier are not otherwise earthed, then it should be appreciated that the only earth connection in the loop will be that of the zener barrier. Thus, as has been explained in earlier chapters, it is not possible to obtain a fully floating system using zener barriers. If one side of the low voltage power supply (normally the negative) is not also earthed, then any earth fault throughout the circuit, regardless of whether the fault occurs on the non-hazardous or hazardous area side of the barrier, will flow via the barrier.

Whilst this may not be especially problematical if single channel barriers have been used, with dual channel barriers the fault current will flow via the fuse in the return barrier channel and may cause the fuse to rupture. (See Figure 14.7)

Furthermore, since the fault current may be significant, the fault could result in failing all the barriers on the system.

This is a common problem with circuits such as fire detection loops which are normally the subject of a battery back-up supply, the negative of which is not earthed. These arrangements are effectively galvanically isolated from earth apart from the barrier connection. Thus any earth fault in the fire panel or on any non-intrinsically safe circuits emanating from the panel is likely to cause this problem.

(Earth faults on actual intrinsically safe barrier protected circuits will not normally result in blowing the barrier fuse, since the current which may be drawn from these circuits is resistance current limited by the barrier internal resistance to a level which is less than the fusing current. Zener barriers are normally classed as short circuit proof for this reason.)

There are a number of possible ways of overcoming this problem.

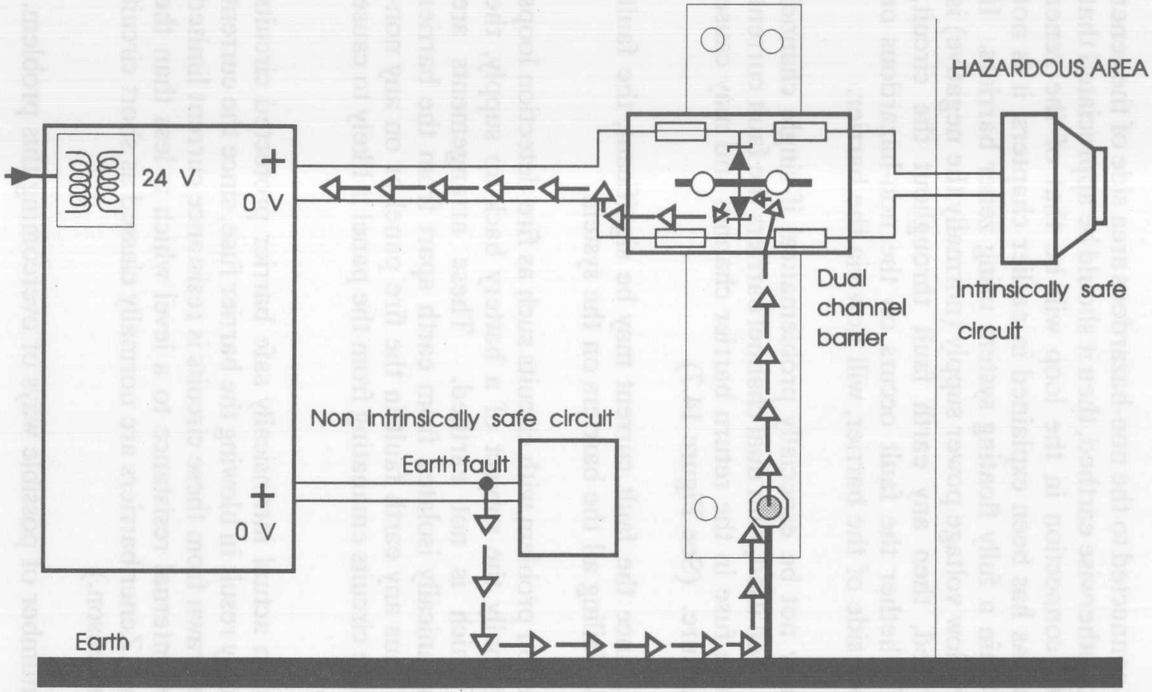

Figure 14.7 *An earth fault anywhere on the circuit may cause the internal barrier fuse to rupture*

- *Galvanic isolation of the intrinsically safe and non-intrinsically safe circuits.*

  If all the intrinsically safe circuits are powered from their own isolating transformer within the panel, then the faults which can result in blowing the barrier(s) are limited to faults between the isolation transformer and the barriers. Thus the most common cause of the fault - earth connections on field wiring of non-intrinsically safe circuits - is removed.

  There is still, of course, the possibility of earth faults within the fire panel between the isolation transformer and the zener barriers.

- *Using galvanically isolating associated apparatus in place of zener barriers.*

  Perhaps the most suitable approach would be to use galvanic isolation instead of zener barriers. This is clearly an absolute solution, although the initial cost of the interfaces will be higher.

  It should be emphasised that for the correct loop monitoring to be carried out [*] the galvanic isolator must be of a type which permits the detection of the various differing current levels required for full line monitoring. This can be achieved with most recent designs of such interfaces, but may not be possible on the earlier units which only permit the sensing of an alarm state, and are, in effect, only suitable for switching circuits.

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* For fire detection circuits, monitoring of short circuit, open circuit, quiescent state and alarm state is a normal requirement. Detection of earth faults may also be necessary.

□ *Using schottky diodes to provide an alternative earth fault return path.*

For some applications, a simple and effective solution is to introduce one or more suitably rated schottky diodes into the circuit on the non-hazardous area side of the zener barrier. The schottky diode(s) should be electrically connected between the zener barrier earth connection and the negative side of the circuit as shown in Figure 14.8.

The low forward volt drop of the schottky diode presents a preferred return path for any earth fault current and will normally prevent the barrier internal fuse from being ruptured. The schottky diode must be of sufficient power rating to be able to cater for any earth fault which is to be considered. For this reason it may be advisable to use individual schottkys on each barrier circuit.

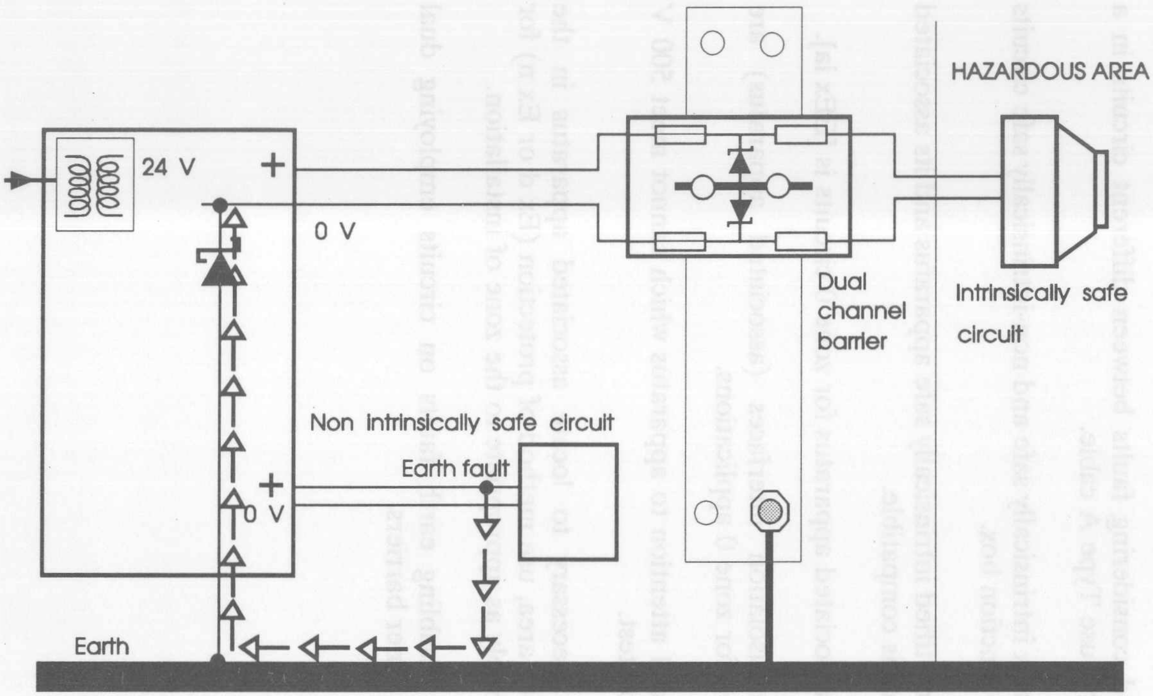

Figure 14.8 *Using a schottky diode to provide an alternative earth fault current path to protect the barrier*

SUMMARY

- □ To avoid considering faults between different circuits in a multicore, use Type A cable.
- □ Do not mix intrinsically safe and non-intrinsically safe circuits in same junction box.
- □ Ensure certified intrinsically safe apparatus and its associated apparatus is compatible.
- □ Ensure associated apparatus for zone 0 circuits is [EEx ia].
- □ Galvanic isolation interfaces (associated apparatus) are preferred for zone 0 applications.
- □ Pay special attention to apparatus which cannot meet 500 V insulation test.
- □ If it is necessary to locate associated apparatus in the hazardous area, use method of protection (Ex d or Ex n) for the assembly as appropriate to the zone of installation.
- □ Beware disabling earth faults on circuits employing dual channel zener barriers.

NOTES AND REFERENCES

1. CENELEC standards require a minimum of 0.2 mm insulation thickness. The UK Code of practice BS 5345: Part 4: 1977 requires 0.3 mm minimum.

2. Because of the additional requirements to consider fault conditions, and the possible temperature which may occur in the interface under such conditions, associated apparatus including zener barriers do not meet Ex e (increased safety) requirements in this respect.

CHAPTER 15

Inspection, Testing, Maintenance and Fault Finding

This chapter includes information on

Record of apparatus
Inspection requirements:
- Initial Inspections
- Routine Inspections

Insulation tests and earth continuity tests
Repairs

NOTE

As throughout this book, the term 'system' in this chapter is used to mean an intrinsically safe circuit loop - normally comprising an interface (associated apparatus), cabling and one or more items of intrinsically safe apparatus connected to that circuit.

Inspection, Testing, Maintenance and Fault Finding

Correct inspection, maintenance and testing is clearly important with all hazardous area electrical apparatus to ensure that, in addition to operational considerations, the method(s) of protection which applies is fully continuing to provide the intended integrity.

This aspect is particularly important with intrinsic safety because the protection is based on system considerations. That is, whereas other methods of protection can be inspected for continued compliance with the relevant requirements on an item-by-item basis, the complete circuit loop needs to be considered as a whole to ensure continued integrity for intrinsic safety.

Additionally, since the safety of the whole loop or system can be jeopardised by modification to any one item in the loop, it is possibly true that intrinsic safety is more susceptible to degradation than other methods of protection.

On the positive side, intrinsic safety is less reliant on mechanical construction than other methods of protection, so there is probably less likelihood of the protection becoming degraded by corrosion, water ingress and so on.

It is well worth bearing these distinctions in mind when approaching inspections and maintenance on intrinsically safe apparatus and systems.

As will be seen, another major difference between intrinsic safety and other protection concepts is that, subject to certain conditions, live maintenance may be carried out on intrinsically safe circuits. This aspect, sensibly and correctly utilised, can make the inspection and maintenance of intrinsically safe systems very much simpler.

This chapter is concerned with all aspects of the care of intrinsically

safe apparatus and systems to ensure that, after installation, the requirements for intrinsic safety continue to be fully achieved. It is important to appreciate that these aspects are not necessarily the same as the requirements to ensure continued correct operation of the circuit from a functional viewpoint. [*]

Record System

There is, for all hazardous area electrical equipment, a requirement to maintain a record system [1] and this is especially important with intrinsic safety since for the inspection to be carried out effectively, every item in the intrinsically safe circuit loop needs to be considered. Although many record systems now employ computer data bases, unless the data base is very sophisticated, there will also be a need for some hard copy information, in the form of systems drawings and commonly a descriptive system document.

In brief, the available information will need to include the following.

For Each Item of Intrinsically Safe Apparatus

Details of manufacturer, type number, serial number

Plant identification number (if appropriate)

Certification code (eg EEx ia IIC T6, etc.)

Certificate number

Details of any special condition of installation or use, including

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* This distinction is crucial since the operational aspects will rarely be ignored because the apparatus and circuit function is necessary for the plant operation and control. However, the fact that a circuit is operating correctly does not necessarily mean that it is (and continues to be) intrinsically safe.

those associated with an 'X' at the end of the certificate number

Sufficient information to identify the system of which the apparatus forms a part

Details of any authorised modification

Details of inspection frequency / last inspection etc.

Details of any special inspection or testing requirement

For Each Intrinsically Safe System

Details of the location of the associated apparatus serving the system

Details of any applicable system certificate, including

certificate number

certification code

certificate system drawing

A system drawing showing location of each item in the system, together with certification details, terminal numbers, junction boxes etc.

A descriptive system document

Details of any special inspection or testing requirements, including earth and insulation checks, etc.

All this information will be needed by personnel who are to carry out inspection and maintenance work both at initial (installation) stage and subsequent routine or periodic inspections.

It should be appreciated that much of the information needed to complete the record system will be taken from certification documents. Anyone who has attempted to obtain such documentation from equipment manufacturers *after the apparatus has been delivered* will know that such a task is almost impossible. The correct time to gather the necessary information is at the system or loop design stage, or when the apparatus is procured. Those who specify hazardous area apparatus for procurement should **always insist on copies of the certificate being supplied by the vendor before the apparatus is accepted on site.**

Initial Inspection

The Code of practice and other applicable standards state a requirement for an initial (as opposed to routine) inspection. The idea of the initial inspection is to ensure that the apparatus and system has been installed correctly and fully conforms to the applicable documentation.

In the author's experience, this initial inspection is all too frequently ignored in the haste to get a new system up-and-running. Subsequently, even if inspections do find something wrong with the basic installation, there is a tendency for the personnel to think that it must be all right because such a fundamental error would have been found years ago. All too often, if the initial inspection is skimped or missed altogether, faults which very significantly reduce the level of safety will go undetected for years and years.

Thus the initial inspection is crucial and should never be avoided. The inspection needs to carefully check all the intended aspects of the intrinsically safe system loop and check that the system is not invalidated by other aspects such as a junction box containing both intrinsically safe and non-intrinsically safe circuits. [2]

It must be clearly understood that this inspection cannot be

undertaken without a knowledge of the area classification of the area concerned. Thus, before any inspection can be undertaken, the gas group(s), zone(s) and temperature class(es) applicable to the installation must be available.

The following points, not intended as an exclusive list, may serve as a guide.

System Considerations

Does every item in the system agree, in respect of certification code and certificate number to the system certificate, descriptive system document etc?

Is the system suitable for the gas group, zone and temperature classification requirements?

Note:

The system normally takes the classification of the least safe item in the system. Thus if the system contains an item of apparatus which is 'ib' certified, the system is only 'ib', even if, say, the associated apparatus is 'ia'. Similarly, if any one item in the system loop is certified IIB, then all the apparatus in the whole system loop is probably only acceptable for IIB (and IIA) even if other items in the loop are certified for IIC.

Temperature classification, which, since it concerns the maximum surface temperature of the item, may be taken on an item-by-item basis. Thus, providing that each item of apparatus within the system has a T-Class appropriate to the place of installation, the fact that some apparatus within the system is classed T4 and some T6 is not necessarily important providing the T4 item is not installed in a location requiring T5 or T6. (The system classification will again take the classification of the worst T-Class of any item in the system.)

Are all the earthing requirements complied with? (See section in this chapter on testing.)

Are the insulation requirements met? (See section in this chapter on testing.)

Do cable parameters conform to requirements? (Especially important where there are long interconnecting cables and/or where the hazardous area is group IIC.)

Is intrinsic safety invalidated by invasion from other (non-intrinsically safe) circuits? (Especially check junction boxes and wiring in the location of the associated apparatus.)

Apparatus Considerations

For each item of apparatus within the system:

Are intended earth connections correct?

Is the apparatus correctly installed? (Glanding, physical mounting, location compliance with 'X' condition etc.) [*]

Is the labelling visible, especially plant identification. (This will enable the certification details and other important information to be checked from the record system in years to come when the certification label is no longer legible.)

Where the apparatus is uncertified simple apparatus, are the requirements for simple apparatus satisfied? (Particularly in respect of temperature classification and insulation from earth.)

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* Glanding, gaskets and the maintenance of a specific IP rating giving ingress protection of IP5X or IP6X may be especially important for intrinsically safe apparatus used where dust hazards are present. (See Chapter 16)

Notice that it is not normally necessary to inspect the apparatus itself for compliance with the intrinsic safety design criteria. This is the manufacturer's responsibility, and he gives an assurance of compliance by fixing the certification label. The end user and installer will not normally have, (and are not expected to have) the knowledge or competence necessary to inspect apparatus to check intrinsic safety design criteria.

Additional Considerations for Associated Apparatus

Is the interface type number correct? (Quite often one certificate will cover a range of different zener barriers etc. So just checking the certificate number is not a guarantee that the correct barrier has been used.)

Is the segregation between the wiring on the hazardous area side and the non-hazardous area side of the associated apparatus clear and well defined?

If appropriate (zener barriers etc.) is the earth connection correctly installed and is the apparatus correctly insulated from the cabinet / enclosure at the point of installation?

Are there two earth conductors [*] and are they correctly terminated to the power system earth?

Is the point at which the earth conductors connect with the power system earth identified with a suitable label? [3]

Additional Considerations for Portable Apparatus

Is the hazardous area in which the portable apparatus will, or may, be used clearly defined? (If not, then the portable apparatus should be suitable for the most hazardous

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* Using two earth conductors makes testing of earth loop resistance and continuity very much easier. This aspect is covered later in the chapter.

classification on the site - perhaps excepting zone 0 areas.) [4]

Are any restrictions, especially concerning batteries (charging and changing) clearly marked and noted?

Attention to the foregoing points before the intrinsically safe system is cleared for use will flag up any discrepancies and make future inspections both easier and more likely to find future unauthorised modifications.

An initial inspection procedure (as distinct from routine inspections) should also be carried out immediately following any modification to the system, replacement (eg resulting from rectification work) or repair of any apparatus in the system.

Routine or Periodic Inspections

The routine or periodic inspection needs to establish that, *once the system has been installed correctly*, it continues to meet and fulfil all the safety requirements. Thus the routine inspection needs to especially look for the following aspects.

Changes to the area classification

Damage to apparatus and cables

Deterioration to apparatus and cables due to corrosion

Deterioration of connections, especially earth connections, due to corrosion

Replacement of apparatus with non-equivalent apparatus (especially important with associated apparatus)

Replacement of component parts such as fuses, lamps, etc. with non-equivalent or unacceptable components.

Modifications to the intrinsically safe system since the last inspection [*]

Carefully inspect all items of portable apparatus, or self-contained apparatus since such apparatus is particularly susceptible to damage.

Frequency of Routine or Periodic Inspections

Bearing in mind that the idea of periodic inspections is to ensure that the hazardous area electrical apparatus is maintained in a safe and satisfactory condition, it will be appreciated that to a very great extent the period between inspections depends on how quickly deterioration is likely to occur, and will vary from plant to plant.

If the hazardous area is an indoors location, with no corrosive agents present and good control over the system such that unauthorised modifications are not likely to be carried out, then deterioration of the required levels of safety will be relatively slow. On the other hand, a plant where the hazardous area is out of doors, or where there are likely to be corrosive agents or where there is poor control over the site will deteriorate more rapidly.

The IEC technical report 79-17 suggests that routine inspections should never be at intervals exceeding three years, but this is longer than most other guidance which suggests a maximum of two years. Clearly, since the maximum interval applies to all sites, sites which are likely, for whatever reason, to deteriorate more rapidly than an ideal site, will need more frequent inspections.

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* Modifications, in this sense, will usually take the form of alterations or additions to a system configuration rather than modifications to an actual item of apparatus.

The best approach is to determine the inspection frequency for a site using common sense coupled with the results of feedback from previous inspections. If a routine inspection flags up more than a few faults, this is a clear indication that the period between inspections should be reduced. On the other hand, if an inspection finds very little wrong, then a decrease in inspection frequency may be justified.

Recording Results of Inspections

It follows from the above that it is important to record the results of an inspection, and that this information should be reviewed by the responsible senior engineer. Only then can efficient and economic inspections and inspection schedules be managed properly.

Testing

The amount of testing required for intrinsically safe systems is minimal, but there are some essential tests which should be carried out at initial inspection stage and in some instances on a routine basis as well.

Testing of Earth Continuity

The following tests of earth continuity are important for continued intrinsic safety integrity.

Earth Connection to Conductive (metallic) Apparatus Enclosure

It is important to ensure that metallic apparatus enclosures are at the same potential as their surroundings. Since the apparatus is usually attached to the surroundings with metallic

bolts etc. this requirement will normally be satisfied without any difficulty. However, modern hazardous area electrical apparatus with metallic enclosures may include an external earth connection point. [5] This should be connected to a suitable insulated conductor (eg 6 mm^2) whose remote end is terminated to the adjoining steelwork or structure.

Such connections should be checked from time to time. It should be appreciated that if the steel wire armour of a cable is also connected to the enclosure via the cable gland (as is normal practice) [6] then it may be quite difficult to electrically test the direct connection between the enclosure and the surrounding metalwork without first disconnecting cable glands etc. Clearly it would be extremely undesirable to go to these lengths on a routine and regular basis, and there is always the possibility that such activities may actually leave the installation in a less safe condition.

If the direct connection between enclosure and surrounding metalwork is, as intended, only a short distance, then a good visual inspection of the connections at each end of the conductor will normally suffice.

Earth Connections of Steel Wire Armour

Unless there are specific operational reasons to the contrary (in which case they should be fully specified and explained in the descriptive system document) steel wire armour is normally earthed via the enclosure or cabinet at each and every cable gland. Thus an armoured cable serving an intrinsically safe circuit is normally earthed both in the non-hazardous area and in the hazardous area and in effect becomes part of the overall plant equipotential bonding.

Certainly at installation (initial inspection), the continuity (resistance) between the steel wire armour and earth should be tested.

A specific maximum resistance value is not quoted, but compliance with other electrical installation requirements will adequately identify any armour which is not satisfactorily electrically connected to earth.

Earth Connections for Associated Apparatus

Unless the associated apparatus is of galvanic isolator type and/or the safety documentation specifically states that an earth connection is not required, [7] then it should be assumed that the earth connection from the associated apparatus is essential for continued intrinsic safety.

These requirements are fully explained in Chapter 10, and are especially important for interfaces such as zener safety barriers.

Zener barriers are normally mounted on a rail which serves as the interconnection between the zener barrier circuitry and earth. The onward connection from the mounting rail should go directly to the power system earth (neutral) point. The conductor should not also be serving to earth the enclosure in which the associated apparatus is mounted. (See Chapter 10, Figure 10.4.)

If two conductors have been installed, measurement of the resistance or impedance from the barrier installation to the power system earth point is relatively simple as shown in Figure 15.1. It should be noted that the test is being carried out in the non-hazardous area and, electrically, is on the non-hazardous area side of the barrier. Thus there is no need for intrinsically safe test instruments to be used.

The requirement is that the earth loop impedance must not exceed 1 Ω. Since the test is in fact measuring the two leads in series, a reading of less than 2 Ω indicates that each conductor will independently satisfy the requirement.

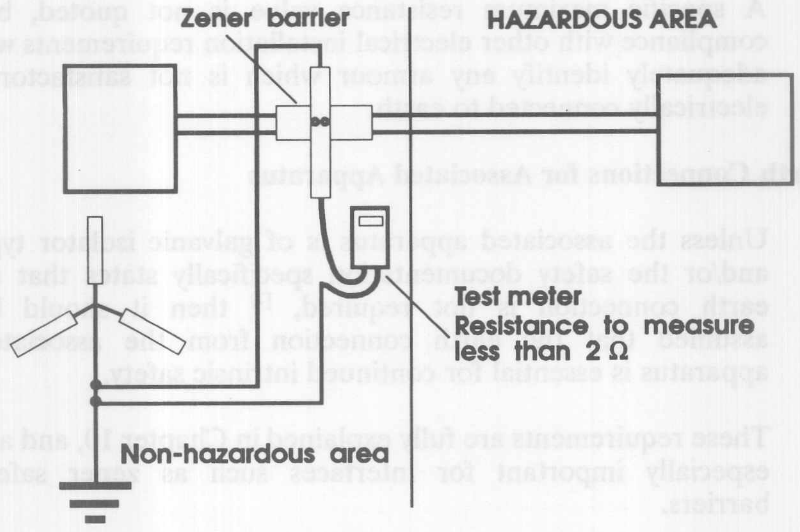

Figure 15.1 *Testing Earth Resistance from the Zener Barrier Installation to the Power System Earth*

Insulation Resistance Testing

As explained in earlier chapters, the intrinsically safe circuit in the hazardous area is normally required to be insulated from earth (or the apparatus enclosure) and should be able to withstand a 500 V insulation test to frame or earth of apparatus.

Certified apparatus will meet this requirement automatically (unless there is a special condition of use indicating otherwise) and does not need to be re-tested. If testing of such apparatus is necessary for any reason, then it is important to understand that the circuit itself should not be stressed to 500 V since this may well damage components within the apparatus. It is the whole circuit with respect to the apparatus case which must meet the insulation requirement. Thus the appropriate test is that shown in Figure 15.2.

The 500 V insulation test should not be carried out in the hazardous area, or on circuits which are still electrically connected to the hazardous area unless the test instrument is certified as intrinsically safe for the hazardous area concerned, or there is a live maintenance / hot work permit in operation. [8]

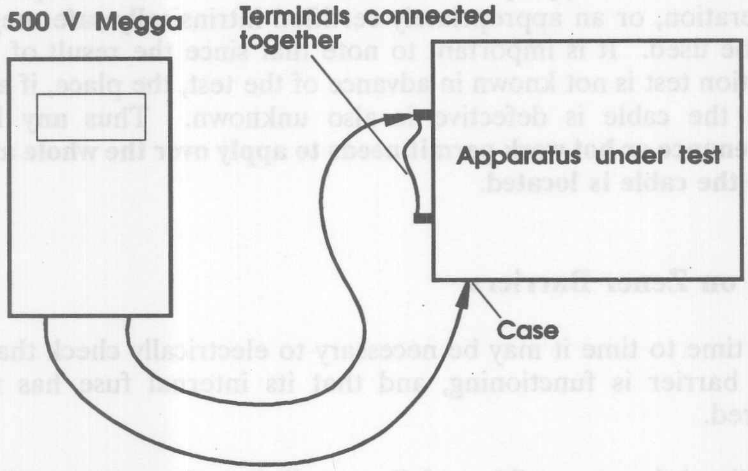

Figure 15.2 *500 V Insulation Resistance Test*

Where items of simple apparatus have been used, there can be no assumption that the circuit will meet the insulation test requirements. Thus items of simple apparatus should always be tested as shown in Figure 15.2. The test should preferably be carried out prior to installation in the hazardous area. If this is not possible, then the precautions already described will apply.

If, for example on apparatus such as thermocouples or conductivity probes, the insulation requirements cannot be met, then there must either be some galvanically isolating apparatus in the system loop (possibly the associated apparatus) or there must be an additional earth bond as shown in Chapter 14, Figure 14.2.

Cables should be tested for insulation resistance at installation. On new sites, this work can clearly be carried out before the flammable atmosphere is present, and thus does not require intrinsically safe meggers or hot work permits. Where it is necessary to test cables **any part of which pass through a hazardous area** after the plant is operational and the flammable atmosphere may be present, there must either be an appropriate live maintenance or hot work permit in operation, or an appropriately certified intrinsically safe megga must be used. It is important to note that since the result of the insulation test is not known in advance of the test, the place, if any, where the cable is defective is also unknown. Thus **any live maintenance or hot work permit needs to apply over the whole area where the cable is located.**

Tests on Zener Barriers

From time to time it may be necessary to electrically check that a zener barrier is functioning, and that its internal fuse has not ruptured.

In reality, it is not possible to fully test all the safety aspects of the zener barrier without sending the unit back to the manufacturer. Those who attempt to carry out a full test frequently end up rupturing the internal fuse by doing the test!

The only practical test which should be carried out on the zener barrier is a check of end-to-end resistance. (Figure 15.3.) This will confirm that the fuse is intact. In reality, the fuse will always fail before any other components within the barrier are damaged.

Remember to check both channels within the barrier if it is a dual channel type, and remember that barriers with 'diode return channels' (see Chapter 11 Figure 11.5) will not respond to a resistance test because of the series diodes. Since there are normally three such diodes in the line, a diode continuity test from

a multimeter may also not give a good response. [*]

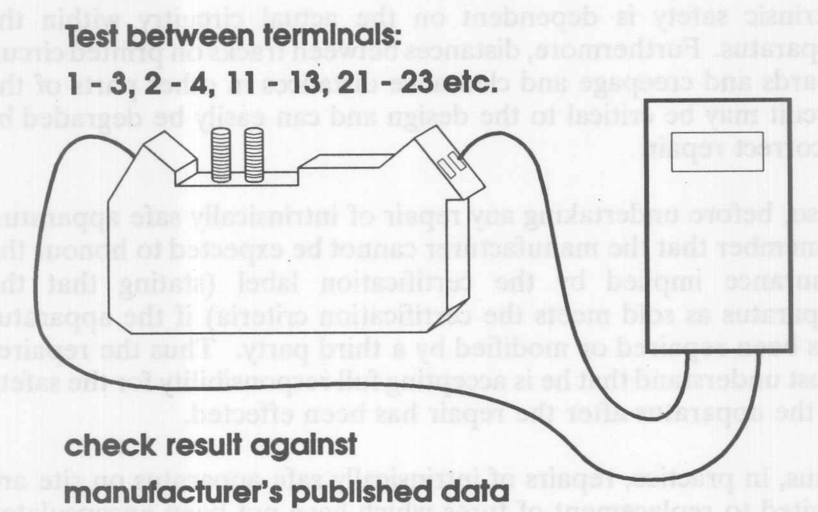

Figure 15.3 *Testing Zener Barrier end-to-end Resistance*

Repairs to Intrinsically Safe Apparatus

The extent of repairs which can be carried out on intrinsically safe apparatus by the user is fairly limited, and in most situations apparatus will need to be returned to the manufacturer. Some items, such as zener safety barriers, are not repairable, and if the internal fuse is blown then the unit is scrap.

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* I have a diode test position on two multimeters. One satisfactorily tests the diode return channel of zener barriers, the other does not. It is worth experimenting with a barrier you know is working properly. The diode test position on many multimeters is quite sensitive to the battery condition, so ensure the meter has new or freshly charged batteries.

Unlike some of the other methods of protection where the prime protection aspect is the enclosure, it should be remembered that intrinsic safety is dependent on the actual circuitry within the apparatus. Furthermore, distances between tracks on printed circuit boards and creepage and clearance distances in other parts of the circuit may be critical to the design and can easily be degraded by incorrect repair.

Also, before undertaking any repair of intrinsically safe apparatus, remember that the manufacturer cannot be expected to honour the assurance implied by the certification label (stating that the apparatus as sold meets the certification criteria) if the apparatus has been repaired or modified by a third party. Thus the repairer must understand that he is accepting full responsibility for the safety of the apparatus after the repair has been effected.

Thus, in practice, repairs of intrinsically safe apparatus on site are limited to replacement of fuses which have not been encapsulated into the circuit, filament bulbs, LED's and similar components.

Extreme care should be taken with replacement fuses, and if there is any doubt concerning the replacement type, obtain the correct fuse from the apparatus manufacturer.

It is extremely rare that other components such as resistors and diodes will fail in intrinsically safe apparatus, since they are almost always used well below their normal rating as a result of the design requirement for a factor of safety of 1.5 and may well be protected by a fuse anyway. On no account should personnel attempt to repair circuits where components such as these need replacement, since they may well be safety components whose specification and fitting is critical.

Apparatus which has been badly damaged, or where the repair is likely to involve safety dependent components must be returned to the manufacturer. The manufacturer should be asked to provide a

letter, with the repaired apparatus, stating that it still conforms to the original certification.[*]

Use of 'Approved Repairers'

There may be instances where, for example by reason of geographical location, it is convenient to send apparatus for repair to an organisation other than the manufacturer. In some instances, manufacturers have set up agents as repairers.

Remember that you will be relying on the repairer's quality assurance organisation for your assurance that the apparatus is still safe when it is returned. Unless the repairer is also a manufacturer of certified products (albeit not the same products as the one you want repaired) then his organisation will not have been audited by the nominated body. Furthermore, even if he is audited by a nominated body, that audit will normally only be looking for aspects which are relevant to the certificates he holds. Thus, if the repairer is actually a motor manufacturer, holding certificates for flameproof motors, then it does not follow that he is necessarily competent to repair intrinsically safe instrumentation.

If a third party repairer is to be used, the following points should be considered.

- ☐ Does the manufacturer and certificate holder for the apparatus recognise the repairer?

- ☐ Has the repairer been audited by a nominated body as a result of holding certificates for other apparatus?

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* In fact, as has been explained elsewhere, the manufacturer automatically gives this attestation when fixing the certification label. Thus if the apparatus is returned with the certification label intact, then is it reasonable to assume that such assurance does still apply.

- ☐ Will the manufacturer release the necessary drawings and design information to enable the repairer to identify safety critical aspects of the design?

- ☐ Will the repairer have access to all the necessary information, including certification and design drawings from the manufacturer?

- ☐ Will the repairer attest that the repaired apparatus fully conforms to the appropriate standards *and to the certification conditions*?

Careful consideration of the responses to questions such as those indicated above will determine whether the use of third party repairers is acceptable.

Static Risks

Particular care should be taken when working on apparatus with non-conductive (plastic) enclosures. Such apparatus should always be carefully cleaned with a damp cloth to minimise the risk of static build up. Incorrect cleaning can give rise to the build up of significant static charges.

SUMMARY

- □ A record system must exist, and be kept up-to-date, covering all the intrinsically safe apparatus and systems on the site.
- □ The information necessary to set up the record system should be collected no later than the apparatus procurement stage and should include copies of certificates, system drawings etc.
- □ An initial inspection must always be carried out before the intrinsically safe system is first activated and again if there has been any modification, repair, etc. to any part of the system loop.
- □ Routine inspections should be carried out at sufficient frequency to ensure continued safety integrity.
- □ Electrical testing is normally confined to insulation tests and earth testing.
- □ Unless the test can be performed using test apparatus which is itself safe and suitable for the hazardous area and for connection to intrinsically safe circuits, then a live maintenance permit must be in force even for intrinsically safe apparatus and systems.
- □ Excepting simple repairs such as the replacement of fuses, intrinsically safe apparatus should normally be returned to the manufacturer for repair.

NOTES AND REFERENCES

1. The requirement for a record system is detailed in the UK Code of practice, BS 5345, in IEC 79-17 'Electrical apparatus for explosive gas atmospheres, Part 17: Recommendations for inspection and maintenance of electrical installations in hazardous areas (other than mines)' and in various legislation, EC Directives etc.

2. It may be possible for both intrinsically safe and non-intrinsically safe circuits to be present in the same junction box, although the practice should be avoided if at all possible. Where it is unavoidable then the following aspects should be carefully considered.

   - The wiring and terminals within the junction box need to meet specific segregation requirements. (See Chapter 13)

   - Junction boxes which contain non-intrinsically safe circuits are not included within the permitted live maintenance for intrinsic safety. This may mean, unless there is a separate live maintenance permit in operation, that the intrinsically safe system cannot be fully inspected using live maintenance principles.

   - The junction box should certainly carry a **warning** label indicating that it **contains both intrinsically safe and non-intrinsically safe circuits**.

3. The connection point for the earth conductor remote from the associated apparatus, should be identified with a label stating EARTH CONNECTION FOR INTRINSICALLY SAFE CIRCUITS. DO NOT REMOVE.

4. Since zone 0 areas are normally inside process vessels and tanks, it is normally accepted that portable apparatus will not be used in zone 0 areas. If it is necessary to take portable

apparatus into a tank or process vessel, then the area will normally be carefully purged or cleaned first, thus removing the hazard and having the effect of temporarily rescinding the zone 0 classification, or enabling a live work permit to be issued. Most portable apparatus is thus only designed and certified to 'ib' conditions.

5. Although external earth connections may be included on some intrinsically safe apparatus, they are not a requirement. The general requirements standard (EN 50 014, clause 15.2) states that an external earth connection facility shall be provided on apparatus with metallic enclosures, but the intrinsic safety standard EN 50 020 specifically excludes clause 15 of the general standard from applying to intrinsic safety.

6. See Chapter 10.

7. It is becoming increasingly common for some earth fault detection apparatus to be permanently connected alongside the associated apparatus. Such apparatus frequently takes the form of an additional module of similar appearance to the interface itself. For the earth fault monitoring circuit to function, it will require an electrical connection to earth and thus even where associated apparatus does not require an earth connection for intrinsic safety purposes, such a connection may still be required for operational reasons.

8. It should be remembered that the use of an intrinsically safe test meter does not automatically allow live testing on methods of protection which are not themselves intrinsically safe. In order to open such apparatus and access the terminals or circuitry the apparatus must either be isolated, or a live maintenance permit must be in force.

CHAPTER 16

Intrinsic Safety and Dust Hazards

This chapter includes information on
Nature of dust hazards Classification of dust hazards Ingress protection requirements Insulating and conducting dusts Temperature considerations Typical data for dusts

NOTE

Some of the distinctions between the treatment of apparatus for dust hazards and gas/vapour hazards with intrinsic safety also apply to other methods of protection. The use of other methods of protection such as flameproof or increased safety is beyond the scope of this book, but it is important to appreciate that additional consideration may be necessary for methods of protection other than intrinsic safety and apparatus certified for group II is not necessarily suitable for dust hazard environments.

Intrinsic Safety and Dust Hazards

Most of the methods of protection, including intrinsic safety, have been developed primarily for use in hazardous areas where the potentially flammable substance is a gas or vapour. Where the hazard is a dust, different conditions apply. This distinction has, at least in part, been the reason why mining is subject to a separate gas group (group I) and traditionally has had separate certification procedures which often require greater emphasis on mechanical protection.

In recent years very much more work has been done on dust hazards and several new standards have been published relating to the use of electrical apparatus in dusty environments. The problems of dust hazards are not confined to the mining industry; food handling and processing plants, flour mills, grain silos, sugar refineries, breweries, plant concerned with the bagging of powders and so on are all likely to have potentially explosive atmospheres caused by dusts.

In this chapter the use of intrinsic safety in areas likely to be subjected to dust hazards is considered and the impact of new standards is examined.

There is a significant difference between the way electrical apparatus is protected for use in gas and vapour hazards and that for dust hazards. The difference stems from two considerations.

- Whereas it is not normally possible to prevent a gas from entering apparatus (that is, apparatus is rarely 'gas tight') [*] it is possible to prevent the ingress of dust.

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* Some methods of protection such as Ex p and Ex o are, in effect, gas tight, or at least prevent gas reaching the source of ignition, but most are not. Methods such as Ex d and Ex e set out to prevent ignition by other means, but not by excluding the possible presence of a flammable atmosphere entering the enclosure.

- Dusts can settle out and then remain where they settle. Thus even small releases of dust can build up in layers, whereas a similar release of a gas or vapour would disperse before another release could 'add' to its effect.

In general, protection of electrical apparatus against dust hazards is achieved by

- adequate sealing of the apparatus to prevent the ingress of dust, and

- having prevented ingress, by careful control of the exposed (external) surface temperature, and

- by designing the enclosure of the apparatus so that pockets or layers of dust accumulation are unlikely and such that the apparatus may be readily kept clean and free of dust build-up.

Whilst these criteria seem to make good sense for methods of protection other than intrinsic safety, they need some review with intrinsic safety since, temperature considerations aside, the problems of spark ignition have been eradicated. [*]

Hazardous Area Terminology for Dust Hazards

Before looking in detail at the application of intrinsic safety to dust hazards, the terminology which is used should be understood.

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* Although it is true that dusts have greater minimum ignition energies than some gas and vapour hazards, the problems of spark ignition are not, in fact, automatically overcome with intrinsic safety because the dust can give rise to reduced creepage and clearance distances. Furthermore, although intrinsically safe apparatus certified for group IIC is almost certainly within the minimum ignition energy requirements for dusts, the same may not be true for apparatus certified for IIB or IIA.

Whereas the gas and vapour hazard classification is based firmly on the IEC terminology, the same is not true with dusts. Thus the terminology used may alter from country to country and care should always be taken to ensure that there is no confusion over the exact meaning of zones.

BS 6467, 'Electrical Apparatus with protection by enclosure for use in the presence of combustible dusts' defines, in Part 2, [1] two zones for dust hazards, zone Z and zone Y. The definitions are as follows.

Zone Z An area in which combustible dust is, or may be, present as a cloud during normal processing, handling or cleaning operations in sufficient quantity to be capable of producing an explosible concentration of combustible or ignitable dust in a mixture with air.

Zone Y An area not classified as Zone Z in which accumulations of layers of combustible or ignitable dust may be present under abnormal conditions and give rise to ignitable mixtures of dust and air. [*]

For both zones Y and Z, the *extent of zone* is defined as the distance, in any direction, from a source of release to the point where the hazard associated with that zone is considered to no longer exist.

It is likely that a system of three zones, similar to those used for gases and vapours will be adopted in the future. The proposed terminology [2] is as follows:

Zone 20 A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously,

---

* Thus zone Y is similar to zone 2 of gas / vapour hazards, and zone Z is similar to zone 1 and 0 (but does not apply to the inside of a dust containment system).

for long periods or frequently and in which deposits of combustible dust of unknown or excessive thickness may be formed. (Dust deposits alone are not grounds for classification as zone 20.)

[*Thus zone 20 ≈ zone 0*]

Zone 21 A place in which a dangerous explosive atmosphere in the form of a cloud of combustible dust in air is likely to occur during normal operation and in which accumulations or layers of combustible dust will in general be present.

[*Thus zone 21 ≈ zone 1*]

Zone 22 A place in which a dangerous explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation, or, if it does occur, will persist for a short period, or in which accumulations or layers of combustible dust are present.

[*Thus zone 22 ≈ zone 2*]

Specific Requirements for Intrinsic Safety

Although not published as a CENELEC Standard, BS 7535: 1992 'Guide to the selection of apparatus complying with BS 5501 [3] or BS 6941 [4] in the presence of combustible dusts' probably gives the best currently available guidance.

The requirements are as follows.

Ingress Protection of Enclosure of Intrinsically Safe Apparatus [*]

For zone Z, the enclosure should provide at least IP6X. [**] For zone Y, the enclosure should provide at least IP5X, unless the dust hazard is electrically conductive, [5] in which case IP6X is required.

Intrinsically safe apparatus which does not have an enclosure meeting these requirements may still be acceptable if it can meet the requirements of a specific assessment for ignition energy and temperature.

Ignition Temperature Considerations

If the enclosure of the intrinsically safe apparatus meets the IP requirements of IP5X or IP6X as appropriate, then no internal assessment is necessary and the only remaining consideration is the surface temperature of exposed (external) surfaces.

The intrinsically safe apparatus will bear a temperature classification, [6] [7] which indicates the maximum exposed surface temperature. The apparatus user will not normally know whether the highest temperature is an internal component or an external surface and should thus assume that the T-Class noted on the label denotes the maximum external surface temperature. This temperature should be no more than:

□ 2/3 of the minimum ignition temperature of the combustible

---

* It should be appreciated that intrinsically safe apparatus does not necessarily provide ingress protection better than IP20. (See Chapter 13). Thus the ingress protection requirements for dust hazards may mean that even certified intrinsically safe apparatus needs additional protection for dust hazard use.

** The second digit of the IP rating defines protection against liquids and is thus not important for these considerations.

dust air mixture(s) (cloud) concerned, and

- 75 K less than the minimum ignition temperature of a 5 mm layer of the combustible dust(s) concerned. [8]

Unless, for example by reference to the certification test report, actual maximum surface temperatures are known, it should be assumed that the maximum surface temperature is the maximum temperature of the temperature class noted on the apparatus.

Ignition Energy and Ignition Temperature Considerations for Intrinsically Safe Apparatus which does not provide the necessary IP Rating

If the above ingress requirements cannot be or are not achieved, then the intrinsically safe circuit should be assessed (and, if necessary, tested) assuming (if appropriate) that all exposed conductors have failed to the most onerous condition. The resulting consideration of energy release should use the criteria applicable to gas group IIC.

Clearly, if the intended application is known, and the dust is not electrically conducting, then creepage and clearance distances will not be altered from the original design. On the other hand, if the apparatus is being assessed for general dust applications, or if the particular dust consideration relates to an electrically conductive dust, then breaching creepage and clearances could have a very significant effect on the intrinsic safety criteria.

For either electrically conducting or non-electrically conducting dusts, the surface temperature considerations will need to take account of the fact that the layer of dust may act as a thermal insulator and thus prevent normal air heat dissipation. The resulting surface temperature may thus be greater than that assessed for certification under group II considerations. Small components, which may have been excluded from full testing under group II

design criteria (see Chapter 6) will need to be tested. They may exceed the specific requirements for ignition of a dust layer, providing the tests show that the dust(s) in question is not ignited or charred by the component.

Except for the specific conditions for small components stated in the previous paragraph, surface temperature requirements should conform to the general criteria stated earlier.

Selection of 'ia' and 'ib' Apparatus according to Zone of Installation

Intrinsically safe apparatus to be used in zone Z should be 'ia' in addition to meeting any or all of the above requirements as applicable.

Intrinsically safe apparatus to be used in zone Y should be either 'ia' or 'ib' and in addition meet any or all of the above requirements as applicable.

Installation and Maintenance Requirements for Intrinsically Safe Apparatus and Systems in Dust Hazards

The installation and maintenance requirements are the same as those for intrinsically safe apparatus and systems in gas or vapour hazards, but it is, of course, especially important to ensure that any required ingress protection is maintained, and additional care should be taken to maintain the apparatus in a clean state.

Classification of Dust Hazards

Whereas established data can usually be used directly when considering area classification for gases and vapours, the available data on dust hazards often requires significant interpretation and

may well need to be supplemented with additional tests. For example, tables of dust data given in BS 7535 and BS 6467 include information for typical dust hazards but the information is only applicable to dusts with the particle size distribution indicated within the tables. Similar dusts with particle sizes differing from the data in the table may have significantly differing ignition properties.

As far as intrinsically safe apparatus is concerned, ignition from spark energy is very rarely a problem, since the likelihood of achieving a homogenous cloud of dust within the apparatus is remote in the extreme.

As will be seen from the following table, the ignition temperature for apparatus which can achieve the necessary IP rating is also unlikely to present difficulties, since intrinsically safe apparatus rarely has temperature classifications higher then T3 (200°C maximum surface temperature).

Table 16.1 gives information on various dust hazards. The information has been compiled from data in BS 7535, BS 6467: Part 2, American National Electrical Code (article 500) and ISA standard S12.10. [9] The information given in the table should be used with caution, since, as explained, differences in particle size and differences in moisture content can have a significant effect on the properties quoted. The data may, however, be useful in providing a starting point for more detailed assessment and classification work. If applicable, specialist advice on the properties of any dust hazard, supported by experimental test data, should be obtained.

Dust	Median Particle size applicable to data given (µm)	Ignition Temperature (°C) of cloud	of layer	Minimum Resistivity (Ω.cm)	Maximum explosion pressure (N.m^{-2})
Aluminium, atomised	36	590	760	5	503 x 10^3
Zinc	10	570	440		330 x 10^3
Toner	10	470		63 x 10^9	
Cellulose	45	520	410		930 x 10^3
Grain	37	510	300	41 x 10^9	
Milk powder (skimmed)	90	540	340		654 x 10^3
Sugar	27	490	460	55 x 10^9	751 x 10^3
Phenolic resin	11	530			613 x 10^3
Synthetic rubber	80	450	240		640 x 10^3
Soya milk	20	620	280		
Sulphur	20	280		56 x 10^9	

Table 16.1 *Flammability Data for Some Dusts*.

NOTE

- Some dusts, eg aluminium and zinc can self-ignite under certain conditions.

- Contaminants such as oil, grease etc. can significantly alter (reduce) the dust layer ignition temperature.

SUMMARY

- □ Dusts can present particular problems because of the formation of layers.
- □ If the dust is electrically conducting crucial creepage and clearance distances may be invalidated.
- □ For intrinsically safe apparatus the IP rating is important.
- □ Surface temperature of components may need re-evaluation for dust hazards.
- □ Great care should be taken to establish dust ignition data for the particular dust concerned. Changes in particle size etc. from that shown in data tables may significantly change flammable properties.

NOTES AND REFERENCES

1. BS 6467: Part 2: 1988 Electrical apparatus with protection by enclosure for use in the presence of combustible dusts: guide to selection, installation and maintenance.

2. At the time of writing, these definitions are still being discussed and may be altered slightly before being finalised. For those readers needing to ensure accuracy of the definition, the relevant standards such as IEC 1241-3, EN 1127-1 should be consulted.

3. BS 5501 ≡ EN 50 014 etc.

4. BS 6941: 1988. Electrical apparatus for explosive atmospheres with type of protection N. This standard is not a CENELEC standard. Once the concept of Ex n has been recognised in a CENELEC standard (EN 50 012 covering Ex n is due for publication in 1995/6) then a European standard equating to BS 6941 will no doubt be considered.

5. 'Electrically conducting dust' is defined in BS 6747 as dust with electrical resistivity less than 10^3 Ωcm. Instrument Society of America standard ISA S12.10 indicates that dusts with resistivities lower than 100 Ωcm or which break down when subjected to a 1000 $V.cm^{-1}$ across a bulk sample are regarded as conductors.

   It has also been suggested that resistivities greater than $5x10^8$ Ωcm may be regarded as insulating, and those dusts with resistivities between 100 Ωcm and $5x10^8$ Ωcm as medium resistive or semi-conducting dusts.

   Although technically, metallic dusts such as aluminium and zinc would appear to have low resistivities, in practice, the rapid oxidation which occurs tends to produce much higher resistivities such that electrical conduction, especially at the

typically lower voltages of intrinsically safe circuits, does not occur.

6. See Chapter 1.

7. Simple apparatus which is uncertified, should be assumed to have a temperature class of T4 or T6 as appropriate. See Chapters 6 and 7 for more details.

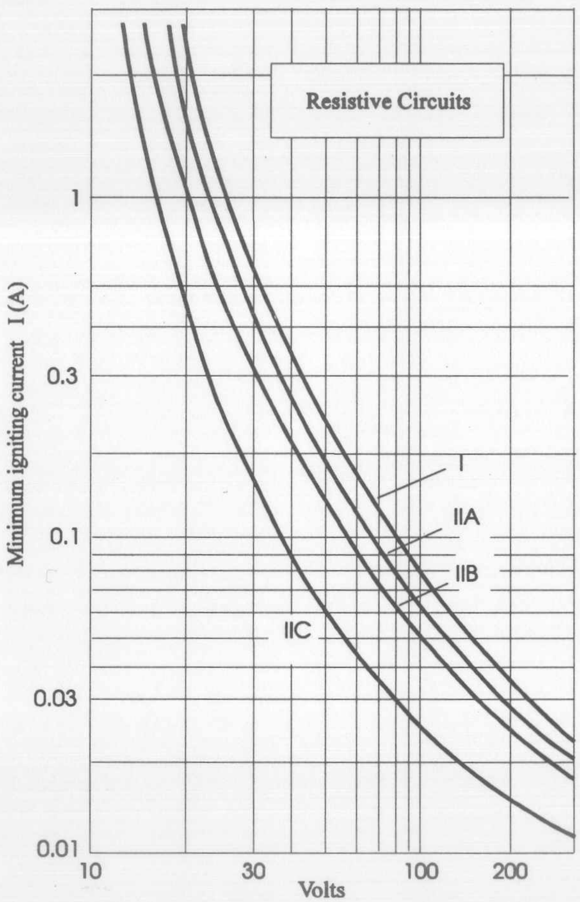
8. EN 1127-1, concerning dust hazards and due for publication in 1995/6 is likely to quote tests with a 12.5 mm layer and a safety factor of 25°C on maximum surface temperature.

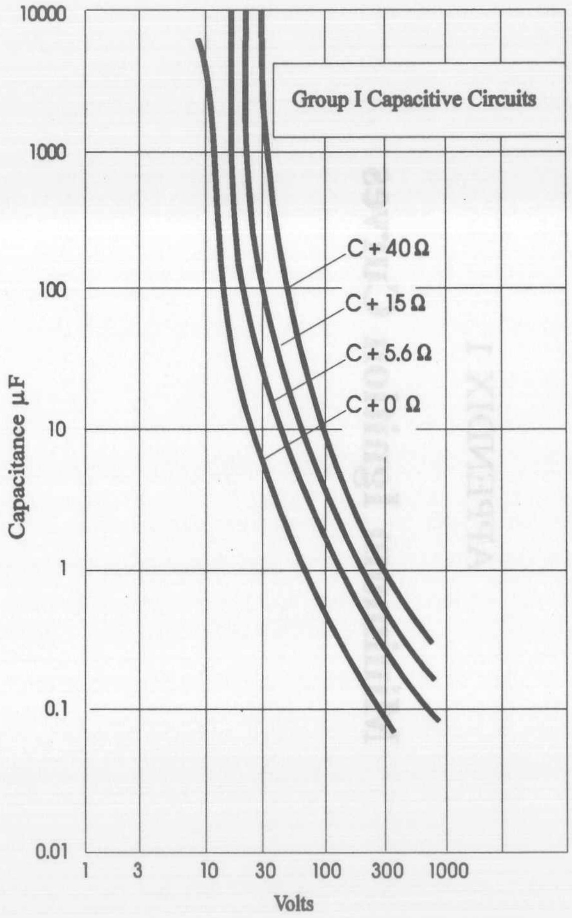
9. Instrument Society of America Standard ISA-S12.10: Area Classification in Hazardous Dust Locations.

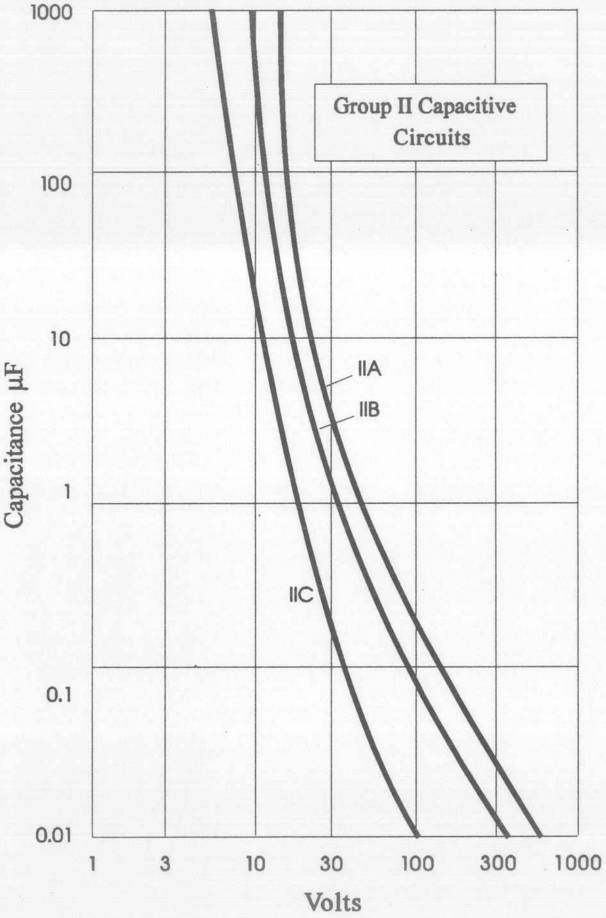
Appendices

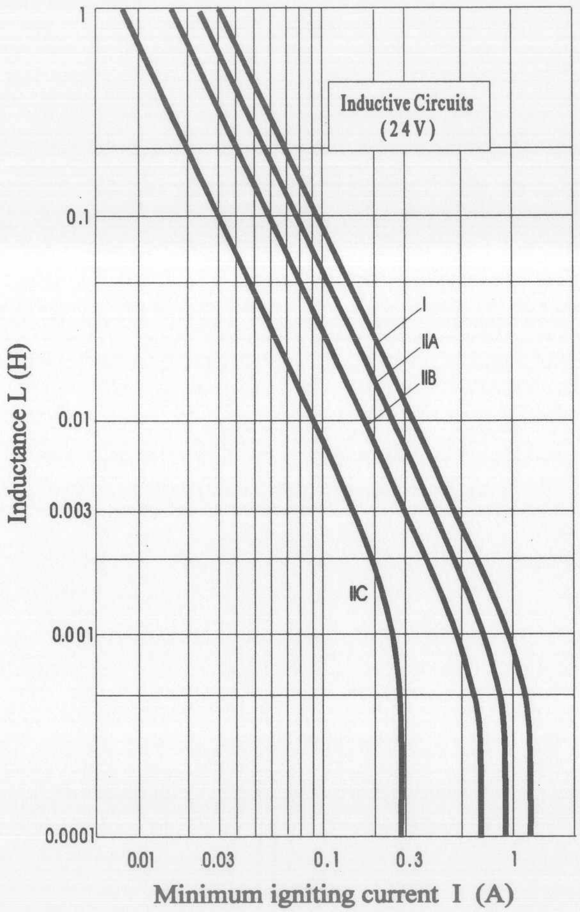
APPENDIX 1

Minimum Ignition Curves


Resistive Circuits
Minimum igniting current I (A)
1
0.3
0.1
0.03
0.01
10
30
100
200
Volts
I
IIA
IIB
IIC


Group I Capacitive Circuits
Capacitance μF
10000
1000
100
10
1
0.1
0.01
1
3
10
30
100
300
1000
Volts
C + 40 Ω
C + 15 Ω
C + 5.6 Ω
C + 0 Ω


Group II Capacitive Circuits
1000
100
10
1
0.1
0.01
Capacitance μF
IIA
IIB
IIC
1
3
10
30
100
300
1000
Volts


Inductive Circuits (24V)
1
0.1
0.01
0.003
0.001
0.0001
Inductance L (H)
I
IIA
IIB
IIC
0.01
0.03
0.1
0.3
1
Minimum igniting current I (A)

APPENDIX 2

Glossary and Definitions

NOTE:
Definitions are *given in italics* followed, where necessary, by a short explanation. Where a definition is the exact wording of a standard - eg EN 50 020 Edition 2 - this is indicated after the definition text.

Associated apparatus

Electrical apparatus which contains both intrinsically safe and non-intrinsically safe circuits and is constructed so that the non-intrinsically safe circuits cannot adversely affect the intrinsically safe circuits.

[EN 50 020 Edition 2]

Associated apparatus will normally be located in the non-hazardous area unless the associated apparatus itself is protected with an alternative method of protection.

Associated apparatus includes such items as zener safety barriers and galvanic isolation interfaces. Refer to Chapters 5 and 11 for further details.

Categories of intrinsic safety

ia

Category 'ia' intrinsically safe apparatus shall be incapable of causing ignition in normal operation (including any non-countable fault conditions) and with either one or two countable faults (plus any non-countable faults).

A factor of safety of 1.5 is required under normal operation and under one countable fault. A factor of safety of 1 is required with two countable faults. Temperature assessment is made with a factor of safety of 1.

ib

Category 'ib' intrinsically safe apparatus shall be incapable of causing ignition in normal operation (including any non-countable fault conditions) and with one countable fault (plus any non-countable faults).

A factor of safety of 1.5 is required under normal operation and under one countable fault. Temperature assessment is made with a factor of safety of 1.

Comparative tracking index CTI

The numerical value of the maximum voltage in volts at which, under specified test conditions, the material withstands 50 drops of a test solution without evidence of tracking.

[IEC 112:1979]

The test solution is normally 0.1% by mass ammonium chloride in distilled water.

The comparative tracking index determines the ease with which an electrical path can track across the surface of a solid insulating material.

Division (North America)

The division number defines the likelihood of a hazardous (flammable) atmosphere being present in a particular location.

There are two divisions, division 1 and division 2. Division 2 is approximately the same as zone 2, whilst division 1 is approximately equivalent to zones 0 and 1.

The North American division may not necessarily be evaluated in the same way as a zone. The term division should not, therefore, be used interchangeably with zone.

The term division as applied in the UK under the definition of CP 1003: Part 1: 1964 is no longer used.
Also see zone

Faults

Countable fault

A fault which occurs in parts of a circuit which conforms to the requirements of the standard against which assessment is being made.

Such faults can generally be applied in the most onerous position, either by shorting or open circuiting the conductors and components in the circuit. Faults cannot, however, be applied to infallible circuit tracking, infallible insulations or infallible components.

Non-countable fault

A fault which occurs in a part of the circuit which does not conform to the requirements of the standard against which assessment is being made.

In the assessment of intrinsically safe designs, such faults are assumed to have occurred without being counted for the purposes of defining fault counts for 'ia' or 'ib'.

Hazardous area

An area in which explosive atmospheres [gas / vapour / dust + air mixtures] *are, or may be expected to be, present in quantities such as to require special precautions for the construction and use of electrical apparatus.*

[BS 5345: Part 1: 1989]

The term 'area' in this context, is used to denote a three dimensional space.

Infallible component or infallible assembly of components

A component or assembly that is not likely to become defective, in service or is storage, in such a manner as to invalidate intrinsic safety. [EN 50 020 Edition 2]

Infallible components cannot be considered as failing to a dangerous condition when assessing fault counts.

Infallible separation or insulation

Separation or insulation between electrically conductive parts that is not considered as becoming short circuited in service or storage and therefore will not be considered to fail for the purposes of fault analysis and the application of the spark test apparatus.

[EN 50 020 Edition 2]

Intrinsic safety

A protection technique based upon the restriction of electrical energy within apparatus and of interconnecting wiring, exposed to a potentially explosive atmosphere, to a level below that which can cause ignition by either sparking or heating effects.

[BS 5345: Part 4: 1977]

Because of the method by which intrinsic safety is achieved it is necessary to ensure that not only the electrical apparatus exposed to the potentially explosive atmosphere but also other electrical apparatus with which it is interconnected is suitably constructed.

Intrinsically safe circuit

A circuit in which any spark or any thermal effect produced in the conditions specified in the applicable standard and including conditions of normal operation and specified fault conditions, is not capable of causing ignition of a given explosive atmosphere.

Intrinsically safe electrical apparatus

Electrical apparatus in which all the circuits are intrinsically safe.

[EN 50 020 Edition 2]

> Intrinsically safe electrical apparatus is normally contained within a single enclosure.

Intrinsically safe system

Two or more items of electrical apparatus and interconnecting wiring in which any circuits intended for use in a potentially explosive atmosphere are intrinsically safe.

> At least one of the items of electrical apparatus will normally be associated apparatus, unless the system is completely portable (eg some intrinsically safe battery powered apparatus with a plug in probe).
>
> The items of hazardous area apparatus may be either simple apparatus or other (normally certified) intrinsically safe apparatus.

Maximum external inductance to resistance ratio L_o/R_o

Ratio of inductance (L_o) to resistance (R_o) of any external circuit that

can be connected to the connection facilities of the electrical apparatus without invalidating intrinsic safety.

[EN 50 020 Edition 2]

The L/R ratio is used to determine inductive energy in interconnecting cables. See Chapters 5 and 11.

Maximum input current I_i

Maximum current (peak ac or dc) that can be applied to the connection facilities for intrinsically safe circuits without invalidating intrinsic safety.

[EN 50 020 Edition 2]

Maximum input voltage U_i

Maximum voltage (peak ac or dc) that can be applied to the connection facilities for intrinsically safe circuits without invalidating intrinsic safety.

[EN 50 020 Edition 2]

Maximum internal capacitance C_i

The total equivalent internal capacitance of the apparatus which is considered as appearing across the connection facilities of the apparatus.

[EN 50 020 Edition 2]

C_i is the same as C_{eq}

Maximum internal inductance L_i

The total equivalent internal inductance of the apparatus which is considered as appearing across the connection facilities of the apparatus.

[EN 50 020 Edition 2]

L_i is the same as L_{eq}

Maximum output power P_o

The maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.

[EN 50 020 Edition 2]

Also referred to as P_{max} or $P_{max\ out}$

Maximum output voltage U_o

The maximum output voltage (peak ac or dc) in an intrinsically safe circuit that can appear under open circuit conditions at the connection facilities of the apparatus at any applied voltage up to the maximum voltage , including U_m and U_i.

[EN 50 020 Edition 2]

The definition also applies to U_z as used for associated apparatus.

Maximum rms ac or dc voltage U_m

Maximum voltage that can be applied to the non-intrinsically safe

connection facilities of associated apparatus without invalidating intrinsic safety.

[EN 50 020 Edition 2]

Non-hazardous area

An area in which explosive gas + air mixtures are not, and are not expected to be, present in quantities such as to require special precautions for the construction and use of electrical apparatus

The term 'area' in this context is used to denote a three dimensional space.

Non-simple apparatus and components

Apparatus or components which, because they contain electrical energy storing or generating elements can influence the intrinsic safety criteria of an intrinsically safe system.

See Chapter 8 for full explanation.
Non-simple apparatus will be 'certified' intrinsically safe apparatus.

Safe area See non-hazardous area

Self-contained intrinsically safe apparatus

Intrinsically safe apparatus which does not require electrical connection to other apparatus or circuits.

Such apparatus will normally be portable or battery powered apparatus.

Simple apparatus and components

Non-energy storing or generating apparatus or components with well defined parameters which thus will not have any influence on the criteria for intrinsic safety within an intrinsically safe system.

See Chapter 7 for full explanation and limiting parameters.

In general, simple apparatus can be added to an existing intrinsically safe system without further certification or assessment of intrinsic safety.

Spark test apparatus

Apparatus used (eg by a nominated body) for the assessment of an intrinsically safe circuit.

The construction and use of spark test apparatus is detailed in EN 50 020, IEC 79-3, etc.

Zone

The zone number indicates the likely frequency of occurrence and duration of an explosive atmosphere within a hazardous area.

Zone 0 - likely to be present continuously or for long periods, zone 1 - likely to be occur in normal operation, zone 2 - not likely to occur in normal operation, or, if it does occur, will only do so infrequently and will only exist for a short period.

APPENDIX 3

Useful Names and Addresses

SECTION 1: EEC APPROVED TEST BODIES

At the time of going to press, the organisations marked with an asterisk (*) are cited in the EEC Directives, and apparatus certified by them may bear the Distinctive Community Mark, in addition to their own Approved Test Body mark. As membership of the EC changes, so those organisations which are nominated bodies will change.

NOTE

In the information which follows, telephone numbers and fax numbers are given complete with international dialing codes.

AUSTRIA

BVFA/ ETI — Bundesversuchs-und Forschungsantalt Arsenal
Electrotechnisches Institut

ETI
Abt. Elektnsche Sicherhiet
Faradaygasse 3
Postfach 8
A-1030 Wein
Austria

Tel / Fax (00 43) 1 386283

TUV — Technischer Uberwachungsverein

TUV
Krugerstrasse 16
A-1015 Wein
Austria

Tel (00 43) 1 51407

BELGIUM

ISSEP Institut Scientifique Service Public

* ISSEP
60 Rue Grande
B7260 Colfontaine
Belgium

Tel (00 32) 65 61 0811 Fax (00 32) 65 61 0808

DENMARK

DEMKO Danmarks Elektriske Materialkontrol

* DEMKO
Lyskaer 8
2730 Herlev
Denmark

Tel (00 45) 44 94 7266 Fax (00 45) 44 94 7261

FRANCE

INERIS Institut Nationale de l'Environment Industries et des Risques

* INERIS
Park Technologique Alata
PO Box No 2
60550 Verneuil-en-Halatte
France

Tel (00 33) 44 55 6677 Fax (00 33) 44 55 6699

LCIE Laboratoire Central des Industrial Electriques

* LCIE
33 Avenue du General Leclerc
92260 Fontenay-aux-Roses
France

Tel (00 33) 1 40 95 6060 Fax (00 33) 1 40 95 6003

GERMANY

PTB Physikalisch-Technische Bundesanstalt

* PTB
Bundesalle 100
D-38116 Braunschweig
Germany

Tel (00 49) 531 5920 Fax (00 49) 531 5929292

BVS

* BVS
Beylingstrasse 65
D-4600 Dortmund 14
Germany

Tel (00 49) 231 2491226 Fax (00 49) 231 2491224

ITALY

CESI Centro Elettrotecnico Sperimentale Italiano

* CESI
Via Rubattino 54
I-20134 Milano
Italy

Tel (00 39) 2 21251 Fax (00 39) 2 2125440

NORWAY

NEMKO Norges Elektnske Materiellkontrol

NEMKO
Gaustadallen 30
Postboks 288
Blindern
Oslo 3
Norway

Tel (00 47) 22 691950 Fax (00 47) 22 698636

SPAIN

LOM Laboratorio Oficial Jose Maria Madariaga

* LOM
Alenza 2
E 28003 Madrid
Spain

Tel (00 34) 1 442 1987 Fax (00 34) 1 441 9933

SWEDEN

SP	Statens Provningsanstalt

SP
Brinellgaten 12
Box 857
51015 Boras
Sweden

Tel (00 46) 33 165000 Fax (00 46) 33 135502

SWITZERLAND

SEV	Schweizenscher Elektrotechnischer Verein

SEV
Seefeldstrasse 301
CH-8008
Zurich
Switzerland

Tel (00 41) 1 384 9111 Fax (00 41) 1 551426

UK

EECS	Electrical Equipment Certification Service
BASEEFA	British Approvals Service for Electrical Apparatus in Flammable Atmospheres

* BASEEFA
Health & Safety Executive
Harpur Hill
Buxton
Derbyshire
SK17 9JN

Tel (00 44) 01298 28000 Fax (00 44) 01298 28244

MECS Mining Equipment Certification Service

* MECS
Harpur Hill
Buxton
Derbyshire
SK17 9JN

Tel (00 44) 01298 28000 Fax (00 44) 01298 28244

SCS Sira Certification Services Limited

* SCS
Saighton Lane
Saighton
Chester
CH3 6EG

Tel (00 44) 01244 332200 Fax (00 44) 01244 332112

SECTION 2: OTHER TEST AND APPROVALS ORGANISATIONS

CANADA

CSA Canadian Standards Association

CSA
178 Rexdale Boulevard
Rexdale
Ontario
M9W 1R3
Canada

Tel (001) 416 747 4000 Fax (001) 416 747 4149

USA

UL Underwriters Laboratories

UL
333 Pfingsten Road
Northbrook
Ilinois 60062
USA

Tel (001) 708 272 8800 Fax (001) 708 272 8129

FM Factory Mutual Research

FM
1151 Boston Providence Turnpike
Norwood
MA 02062
USA

Tel (001) 617 762 4300 Fax (001) 617 762 9375

SECTION 3: ADDRESSES OF GENERAL USE

CENELEC European Committee for Electrotechnical
Standardization

Central Secretariat
rue de Stassart 35
B-1050 Brussels

BSI
British Standards Institution
389 Chiswick High Road
London
W4 4AL

ISA
Instrument Society of America
67 Alexander Drive
PO Box 12277
Research Triangle Park
NC 27709
USA

ANSI
American National Standards Institute
1430 Broadway
New York 10018
USA

NFPA
National Fire Protection Association
Batterymarch Park
Quincy
MA 02269
USA

Institute of Petroleum

61 New Cavendish Street
London
W2M 8AR

APPENDIX 4

Standards and Comparison Tables

PROTECTION METHOD	CODE [1]	CENELEC	BRITISH	IEC	USA
FLAMEPROOF PROTECTION	Ex d	EN 50 018	BS 5501 PT 5 BS 4683 PT 2 BS 229	79-1	UL898
INCREASED SAFETY	Ex e	EN 50 019	BS 5501 PT 6 BS 4683 PT 4	79-7	
INTRINSIC SAFETY	**Ex ia/ib**	**EN 50 020 EN 50 039 [2]**	**BS 5501 PT 7 BS 5501 PT 9 [2] SFA 3012 BS 1259**	**79-11**	**FM 3160 UL 913**
ENCAPSULATION	EEx m	EN 50 028	BS 5501 PT 8	79-18	
OIL IMMERSION	EEx o	EN 50 015	BS 5501 PT 2	79-6	UL 698
SAND / POWDER FILLING	EEx q	EN 50 017	BS 5501 PT 7	79-5	
PRESSURIZATION	Ex p	EN 50 016	BS 5501 PT 3	79-2	NFPA 496
SPECIAL PROTECTION	Ex s	-	SFA 3009		
N-TYPE PROTECTION	Ex N / n [3]	(EN 50 021)	BS 4683 PT 3 BS 6941	79-15	

NOTES

1 Ex.. if to a National Standard, EEX if to a CENELEC Standard.
2 Intrinsic safety systems standard.
3 BS 6941 refers to type of protection N, whereas IEC 79-15 (and CENELEC Standard EN 50 021 when published) refer to type of protection n. The method of protection (non-sparking) is the same in both cases.

Table A4.1 *Standards to which Apparatus may be Designed, Specified and Purchased*

METHOD OF PROTECTION	UK CODE OF PRACTICE BS 5345: PART	IEC 79 SERIES STANDARD	CENELEC STANDARD
GENERAL REQUIREMENTS	1	79-0	EN 50 014 ETC
CLASSIFICATION OF HAZARDOUS AREAS	2	79-10 [1]	EN 50 145 [1]
FLAMEPROOF PROTECTION	3	79-17	EN 50 154 [1]
INTRINSIC SAFETY	**4**	**79-17**	**EN 50 154**
PRESSURIZATION	5	79-17	EN 50 154
INCREASED SAFETY	6	79-17	EN 50 154
N-TYPE	7	79-17	EN 50 154
SPECIAL PROTECTION	8		
OIL IMMERSION	9 [2]	79-17	EN 50 154
SAND FILLING	9 [2]	79-17	EN 50 154
ENCAPSULATION	Not published	79-17	EN 50 154

NOTES

1 Due for publication 1995.
2 Not yet published.

Table A4.2 *Standards for the End User: Codes of practice and Installation Guidance*

TYPICAL GAS	IEC 79	CENELEC	BS 5345	BS 229 [1]	BS 1259 [2]	GERMANY VDE 0171	USA NEC 70
METHANE [3]	I	I	I	I	I	1	CLASS I GROUP D
PROPANE	IIA	IIA	IIA	II	2c	1	CLASS I GROUP D
ETHYLENE	IIB	IIB	IIB	IIIa or IIIb	2d	2	CLASS I GROUP C
HYDROGEN	IIC	IIC	IIC	IV	2e	3a	CLASS I GROUP B
ACETYLENE	IIC	IIC	IIC	IV	2f	3c	CLASS I GROUP A
CARBON DISULPHIDE	IIC	IIC	IIC	IV	2f	3b	

NOTES

1 Obsolete standard for flameproof enclosures
2 Obsolete standard for intrinsic safety
3 Methane typifies mining hazards which are classified Group I. Where methane is a surface industry hazard, it is classed as IIA.

Table A4.3 *Comparison of Terminology from Different Standards*

APPENDIX 5

Environmental Protection

There are two systems in common use for defining the amount of protection an enclosure affords against the ingress of dust and liquids. The main system is the IP Code (ingress protection). This is defined fully in IEC 529. The Standard is reproduced by BSI as BS 5490: 1985, and the information is also given in the Code of practice, BS 5345: Part 1.

The IP code uses two digits to specify environmental protection. The first digit signifies the protection against solid matter (dust etc.) and the second digit specifies the protection against liquid (water).

FIRST NUMERAL	DEGREE OF PROTECTION
0	No protection of persons against contact with live or moving parts inside the enclosure. No protection of equipment against ingress of solid foreign bodies.
1	Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, for example, a hand, but no protection against deliberate access to such parts. Protection against ingress of large solid foreign bodies.
2	Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium sized solid foreign bodies.
3	Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 2.5 mm. Protection against ingress of small solid foreign bodies.
4	Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 1 mm. Protection against ingress of small solid foreign bodies.
5	Complete protection against contact with live or moving parts inside the enclosure. Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment enclosed.
6	Complete protection against contact with live or moving parts inside the enclosure. Protection against ingress of dust.

SECOND NUMERAL	DEGREE OF PROTECTION
0	No protection
1	Protection against drops of water. Drops of condensed water falling on the enclosure shall have no harmful effect.
2	Protection against drops of liquid. Drops of falling liquid shall have no harmful effect when the enclosure is tilted at any angle up to 15° from its normal position.
3	Protection against rain or sprayed water. Water falling in rain at an angle of not more than 60° from the vertical shall have no harmful effect.
4	Protection against splashing. Liquid splashed from any direction shall have no harmful effect.
5	Protection against water jets. Water projected by a nozzle from any direction shall have no harmful effect.
6	Protection against conditions on ship's decks. (Deck watertight equipment). Water from heavy seas shall not enter the enclosure under prescribed conditions.
7	Protection against immersion in water: it shall not be possible for water to enter the enclosure under stated conditions of pressure and time.
8	Protection against indefinite immersion in water under specified pressure. It shall not be possible for water to enter the enclosure.

An alternative to the IP code is the NEMA code, which is used extensively in North America. The NEMA code is used to specify both environmental protection and hazardous area suitability. Full details in ICS 1-110.

ENCLOSURES FOR INDOOR NON-HAZARDOUS LOCATIONS								
PROVIDES PROTECTION AGAINST	TYPE OF ENCLOSURE							
	1	2	4	4X	6	11	12	13
Accidental contact with enclosed equipment	yes	yes	yes	yes	yes	yes	yes	yes
Falling dirt	yes	yes	yes	yes	yes	yes	yes	yes
Falling liquids and light splashing	-	yes	yes	yes	yes	yes	yes	yes
Dust, lint, fibres and flyings	-	-	yes	yes	yes	-	yes	yes
Hosedown and splashing water	-	-	yes	yes	yes	-	-	-
Oil and coolant seepage	-	-	-	-	-	-	yes	yes
Oil and coolant spraying and splashing	-	-	-	-	-	-	-	yes
Corrosive agents	-	-	-	yes	-	yes	-	-
Occasional submersion	-	-	-	-	yes	-	-	-

ENCLOSURES FOR OUTDOOR NON-HAZARDOUS LOCATIONS				
PROVIDES PROTECTION AGAINST	TYPE OF ENCLOSURE			
	3	3R	3S	6
Accidental contact with enclosed equipment	yes	yes	yes	yes
Rain snow and sleet	yes	yes	yes	yes
Sleet	-	-	yes	-
Windblown dust	yes	-	yes	yes
Hosedown	-	-	-	yes
Occasional submersion	-	-	-	yes

ENCLOSURES FOR INDOOR HAZARDOUS LOCATIONS										
PROVIDES PROTECTION AGAINST ATMOSPHERES CONTAINING	TYPE OF ENCLOSURE									
	CLASS	GROUP	7A/8A	7B/8B	7C/8C	7D/8D	9E	9F	9G	10
Acetylene	I	A	yes	-	-	-	-	-	-	-
Hydrogen, manufactured gas	I	B	yes	yes	-	-	-	-	-	-
Ethyl ether, ethylene, cyclopropane	I	C	yes	yes	yes	-	-	-	-	-
Gasoline, hexane, naphtha, benzine, butane, propane, alcohol, acetone, natural gas, laquer solvent, benzol	I	D	yes	yes	yes	yes	-	-	-	-
Metal dust	II	E	-	-	-	-	yes	-	-	-
Carbon black, coal dust, coke dust	II	F	-	-	-	-	yes	yes	-	-
Flour, starch, grain dust	II	G	-	-	-	-	yes	yes	yes	-
Fibres, flyings	III		-	-	-	-	yes	yes	yes	-
Methane, with or without coal dust	Mines		-	-	-	-	-	-	-	yes

NOTES

Type 7 and Type 10 are 'explosion proof' enclosures.

Type 8 is oil filled enclosures.

Type 9 is dust explosion proof.

If the installation is outdoors and/or additional protection against the environmental conditions is required, a combination-type enclosure will be needed. Enclosures which meet the requirements of more than one type of enclosure may be designated by a combination of type numbers, the smaller number being given first.

APPENDIX 6

Properties of Gases and Vapours

NOTES

1 The information in this appendix is taken from the following sources:

BS 5345: Part 1: 1989. Code of practice for selection, installation and maintenance of electrical apparatus in potentially explosive atmospheres.
ICI/RoSPA publication No IS91. Electrical Installations in Flammable Atmospheres.
Lange's Handbook of Chemistry, 13th edition. McGraw Hill. ISBN 0 07 016192-5.
Perry's Chemical Engineers' Handbook, 6th edition. McGraw Hill. ISBN 0 07 049479-7.

Entries in the table for vapour pressure have been calculated from data in Lange's Handbook of Chemistry using tabulated values provided and substituting in Antoine's equation.

2 A blank in the table means that data was not available. Expert advice should be sought.

3 Temperature data of auto ignition temperature and T-Class given in brackets () should be regarded as provisional data only, since no confirmation of the data has yet been published.

4 Sublimation temperature is given for boiling point of acetylene.

5 Formula weight for industrial methane is given for CH_4.

FLAMMABLE MATERIAL	MELTING POINT °C	BOILING POINT °C	RELATIVE VAPOUR DENSITY	FLASH POINT °C	FLAMMABLE LIMITS % VOL		AUTO IGNITION TEMP °C [3]	T CLASS [3]	APPARATUS GAS GROUP	MOLECULAR (FORMULA) WEIGHT	VAPOUR PRESSURE (Pa)	
					LEL	UEL					25°C	40°C
acetaldehyde	-123	20	1.52	-38	4	57	140	T4	IIA	44.05		
acetic acid	17	118	2.07	40	5.4	16	485	T1	IIA	60.05		
acetic anhydride	-73	140	3.52	54	2.7	10	(334)	(T2)	IIA	102.09		
acetone	-95	56	2.0	-19	2.15	13	535	T1	IIA	58.08	30785	56593
acetonitrile	-45	82	1.42	5		4.4	523	T1	IIA	41.05		
acetyl chloride	-112	51	2.7	4	5.0		390	T2	IIA	78.5		
acetylene [4]	-81	-84	0.9		1.5	100	305	T2	IIC	26.02		
acrylonitrile	-82	77	1.83	-5	3	17	480	T1	IIA	53.06		
allyl alcohol				21					IIA	58.08		
allyl chloride	-135	45	2.64	-20	3.2	11.2	485	T1	IIA			
allylene	-103	-23	1.38		1.7				IIB			
ammonia	-78	-33	0.59		15	28	630	T1	IIA			
amphetamine		200	4.67	<100					IIA			
aniline	-6	184	3.22	75	1.2	8.3	617	T1	(IIA)	93.13		
benzaldehyde	-26	179	3.66	65	1.4		190	T4	(IIA)	106.12		
benzene	-6	80	2.7	-11	1.2	8	560	T1	IIA	78.11	12689	24369
blast furnace gas					28	70			IIA			
1-bromobutane	-112	102	4.72	<21	2.5		265	T3	IIA	137.03		
bromoethane	-119	38	3.75	<-20	6.7	11.3	510	T1	IIA	108.97		
buta-1, 3-diene	-109	-4	1.87		2.1	12.5	430	T2	IIA	54.09		
butane	-138	-1	2.05	-60	1.5	8.5	365	T2	IIA	58.12		
butanone (MEK)	-86	80	2.48	-1	1.8	11.5	505	T1	IIA	72.11		
butan-1-ol	-89	118	2.55	29	1.7	9	340	T2	IIA	74.12		2359
butyl acetate	-77	127	4.01	22	1.4	8	370	T2	IIA	116.16		
butylamine	-104	63	2.52	-9			(312)	(T2)	IIA	73.14		
but-1-ene	-185	-6	1.95		1.6	10	385	T2	IIA			
carbon disulphide	-112	46	2.64	-20	1.0	60	102	T5	IIC			
carbon monoxide	-205	-191	0.97		12.5	74.2	605	T1	IIA			
chlorobenzene	45	132	3.88	28	1.3	7.1	637	T1	IIA	112.56		
1-chlorobutane	-123	78	3.2	<0	1.8	10	(460)	(T1)	IIA	92.57	13612	25977
chloroethane	-136	12	2.22		3.6	15.4	510	T1	IIA	64.52		

FLAMMABLE MATERIAL	MELTING POINT °C	BOILING POINT °C	RELATIVE VAPOUR DENSITY	FLASH POINT °C	FLAMMABLE LIMITS % VOL		AUTO IGNITION TEMP °C [3]	T CLASS [3]	APPARATUS GAS GROUP	MOLECULAR (FORMULA) WEIGHT	VAPOUR PRESSURE (Pa)	
					LEL	UEL					25°C	40°C
2-chloroethanol	-70	129	2.78	55	5	16	425	T2	IIA	80.52		
chloroethylene	-154	-14	2.15		3.8	29.3	470	T1	IIA	62.5		
chloromethane	-98	-24	1.78		10.7	13.4	625	T1	IIA	50.49		
chloromethyl methyl ether	-103	60							IIA			
1-chloropropane	-123	37	2.7	-18	2.8	10.7	(592)	(T1)	IIA	78.54		
2-chloropropane		47	2.7	-32	2.6	11.1	520	T1	IIA	78.54		
cresol	11	191	3.73	81	1.1		555	T1	IIA	108.14		
crotonaldehyde	-75	102	2.41	13	2.1	15.5	(230)	(T3)	IIB	70.09		
cumene	-97	152	4.13	36	0.88	6.5	420	T2	IIA			
cyclobutane	-91	13	1.93		1.8				IIA	56.1		
cycloheptane		119	3.39	<21					IIA	98.18		
cyclohexane	7	81	2.9	-18	1.2	7.8	259	T3	IIA	84.16	13018	24637
cyclohexanol	24	161	3.45	68	1.2		300	T2	IIA	100.16		
cyclohexanone	-31	156	3.38	43	1.4	9.4	419	T2	IIA	98.15		
cyclohexene	-104	83	2.83	<-20	1.2		(310)	(T2)	IIA	82.15		
cyclohexylamine	-18	134	3.42	32			290	T3	IIA	99.18		
cyclopentane	-93	47		-37			(380)	(T2)	IIA	70.13		
cyclopropane	-127	-33	1.45		2.4	10.4	495	T1	IIA	42.08		
decahydronaphthalene	-43	196	4.76	54	0.7	4.9	260	T3	IIA	138.26		
decane	-30	173	4.9	96	0.8	5.4	205	T3	IIA	142.29		
dibutyl ether	-95	141	4.48	25	1.5	7.6	185	T4	IIB	130.22		
dichlorobenzene	-18	179	5.07	66	2.2	9.2	(640)	(T1)	IIA	147.01		
1,1-dichloroethane	-98	57	3.42	-10	5.6	16	440	T2	IIA	98.96		
1,2-dichloroethane	-36	84	3.42	(5)	6.2	15.9	(413)	(T2)	IIA	98.96	10518	20631
1,1-dichloroethylene		37	3.4	-18	7.3	16	(570)	(T1)	IIA	96.94	80185	135206
1,2-dichloroethylene	-122	33	3.55	-10	9.7	12.8	(440)	(T2)	IIA	96.94		
1,2-dichloropropane	<-80	96	3.9	15	3.4	14.5	555	T1	IIA	112.99		
diethyl ether	-116	34	2.55	<-20	1.7	36	170	T4	IIB	74.12		
diethyl sulphate	-25	208	5.31	104					IIA	154.18		
diethylamine	-50	56	2.53	<-20	1.7	10.1	(310)	(T2)	IIA	73.14		
dihexyl ether	-43	227	6.43	75			185	T4	IIA			

FLAMMABLE MATERIAL	MELTING POINT °C	BOILING POINT °C	RELATIVE VAPOUR DENSITY	FLASH POINT °C	FLAMMABLE LIMITS % VOL		AUTO IGNITION TEMP °C	T CLASS	APPARATUS GAS GROUP	MOLECULAR (FORMULA) WEIGHT	VAPOUR PRESSURE (Pa)	
					LEL	UEL	[3]	[3]			25°C	40°C
di-isobutylene	-106	105	3.87	(2)			(305)	(T2)	IIA	112.22		
di-isopropyl ether	-86	69	3.52	-28	1.4	21	(416)	(T2)	IIA	102.17		
dimethyl ether	-141	-25	1.59		3.7	27			IIB	46.07		
dimethylamine	-92	7	1.55		2.8	14.4	(400)	(T2)	IIA			
dimethylformamide	-61	152	2.51	58	2.2	15.2	(440)	(T2)	IIA	73.1		1339
1,4-dioxane	10	101	3.03	11	1.9	22.5	379	T2	IIB	88.10	4979	10252
1,3-dioxolane	-26	74	2.55	(2)					IIB	74.08		
dipentyl ether	-69	170	5.45	(57)			170	T4	IIA	158.29		
dipropyl ether	122	90	3.53	<21			170	T4	IIB			
ethane	-183	-87	1.04		3.0	15.5	515	T1	IIA	30.07		
ethanethiol	-148	35	2.11	-20	2.8	18	295	T3	IIA	62.13		
ethanol : ethyl alcohol	-144	78	1.59	12	3.3	19	425	T2	IIA	46.07	7965	17991
2-ethoxyethanol		135	3.1	95	1.8	15.7	235	T3	IIB	90.12		
ethoxyethyl acetate		156	4.6	47			380	T2	IIA	132.16		
ethyl acetate	-83	77	3.04	-4	2.1	11.5	460	T1	IIA	88.11	12618	25064
ethyl acetoacetate		180		(84)			295	T3	IIB			
ethyl benzene	-95	135	3.66	15	1.0	6.7	431	T2	IIA	106.17		2866
ethyl chloride	-136	12	2.22		3.6	15.4	510	T1	IIA	64.52		
ethyl cyclobutane			2.0	<-16	1.2	7.7	210	T3	IIA			
ethyl cyclohexane		131	3.87	14	0.9	6.6	262	T3	IIA	112.22		
ethyl cyclopentane		103	3.4	1	1.1	6.7	260	T3	IIA	98.18		
ethyl formate	-80	54	2.55	<-20	2.7	16.5	440	T2	IIA			
ethyl methyl ether		8	2.087		2.0	10.1	190	T4	IIB			
ethylene	-169	-104	0.97		2.7	34	425	T2	IIB			
ethylenediamine	8	116	2.07	34			385	T2	IIA			
ethylene oxide	-112	11	1.52		3.7	100	440	T2	IIB	44.05		
formaldehyde	-117	-19	1.03		7	73	424	T2	IIB	30.03		
formic acid		101	1.6	68			(520)	(T1)	IIA	46.03		
2-furaldehyde		161	3.3	60	2.1	19.3	315	T2	IIA	96.09		
heptane	-91	98	3.46	-4	1.1	6.7	215	T3	IIA	100.21	6092	12332
heptan-1-ol	-34	176	4.03	60					IIA	116.20		

FLAMMABLE MATERIAL	MELTING POINT °C	BOILING POINT °C	RELATIVE VAPOUR DENSITY	FLASH POINT °C	FLAMMABLE LIMITS % VOL		AUTO IGNITION TEMP °C [3]	T CLASS [3]	APPARATUS GAS GROUP	MOLECULAR (FORMULA) WEIGHT	VAPOUR PRESSURE (Pa)	
					LEL	UEL					25°C	40°C
hexane	-95	69	2.97	-21	1.2	7.4	233	T3	IIA	86.18		
hexan-2-one	-56	28	3.46	23	1.2	8	(530)	(T1)	IIA	100.16		
hydrogen cyanide		26	0.90	-18	5.6	40	(538)	(T1)	IIB	27.06		
hydrogen sulphide	-86	-60	1.19		4.3	45.5	270	(T3)	IIB	34.08		
hydrogen	-259	-253	0.07		4.0	75.6	560	T1	IIC	2.016		
isobutyl alcohol	-108	107	2.55		1.7	10.9	408	(T2)	IIA	74.12		
isopropyl nitrate		105		20	2.0	100	175	T4	IIB	105.09		
isopropyl alcohol	-86	83	2.07	12	2.0	12	425	T2	IIA	60.10	6019	14225
kerosine		150		38	0.7	5	210	T3	IIA			
methane (firedamp)	-182	-161	0.55		5.0	15	595	T1	I			
methane (industrial)								T1	IIA	16.04 [5]		
methanol	-98	65	1.11	11	6.7	36	455	T1	IIA	32.04	16671	35089
2-methoxyethanol	-86	124	2.63	39	2.5	14	285	T3	IIB			
methyl acetate	-99	57	2.56	-10	3.1	16	475	T1	IIA	74.08	28830	54081
methyl acetoacetate		170	4.0	67			280	T3	IIA	116.12		
methyl acetylene		-23	1.4		1.7				IIB			
methyl acrylate	<-75	80	3.0	-3	2.8	25			IIB	86.09		
methyl cyclohexane	-127	101	3.38	-4	1.15	6.7	260	T3	IIA	98.19		
methyl formate	-100	32	2.07	<-20	5	23	450	T1	IIA	60.05	83438	
2-methyl propan-1-ol	-108	107	2.55		1.7	10.9	408	(T2)	IIA	74.12		
methylamine	-92	-6	1.07		5	20.7	430	T2	IIA	31.06		
morpholine	-3	128	3.0	(40)			(310)	(T2)	IIA	87.12		
naphtha		35	2.5	-6	0.9	6	290	T3	IIA			
naphthalene	80	218	4.42	77	0.9	5.9	528	T1	IIA	128.17		
nitrobenzene	6	211	4.25	88	1.8		480	T1	IIA	123.11		
nitroethane	-90	115	2.58	27			410	T2	IIB	75.07		
nitromethane	-29	101	2.11	36			415	T2	IIA	61.04		
1-nitropropane	-108	131	3.06	49			420	T2	IIB			
nonane	-54	151	4.43	30	0.8	5.6	205	T3	IIA			1406
octane	-56	126	3.93	13	1.0	3.2	210	T3	IIA	114.23	1859	4139

FLAMMABLE MATERIAL	MELTING POINT °C	BOILING POINT °C	RELATIVE VAPOUR DENSITY	FLASH POINT °C	FLAMMABLE LIMITS % VOL		AUTO IGNITION TEMP °C [3]	T CLASS [3]	APPARATUS GAS GROUP	MOLECULAR (FORMULA) WEIGHT	VAPOUR PRESSURE (Pa)	
					LEL	UEL					25°C	40°C
paraformaldehyde		25		70			300	T2	IIB			
paraldehyde	12	124	4.56	17	1.3		235	T3	IIA	132.16		
pentane	-130	36	2.48	<-20	1.4	8.0	285	T3	IIA	72.15	70912	119534
pentane-2,4-dione	-23	140	3.5	34	1.7		340	T2	IIA			
pentanol	-78	138	3.04	34	1.2	10.5	300	T2	IIA	88.15		
pentylacetate	-78	147	4.48	25	1.0	7.1	375	T2	IIA	130.19		
petroleum				<-20				T3	IIA			
phenol	41	182	3.24	75			605	T1	IIA	94.11		
propane	-188	-42	1.56		2.0	9.5	470	T1	IIA	44.10		
propanethiol									IIB	76.16		
propan-1-ol	-126	97	2.07	15	2.15	13.5	405	T2	IIB	60.10	2779	6985
propan-2-ol	-86	83	2.07	12	2.0	12	425	T2	IIA	60.10	6019	14225
propene	-185	-48	1.5		2.0	11.7	(455)	(T1)	IIA	42.08		
propylamine	-101	32	2.04	<-20	2.0	10.4	(320)	(T2)	IIA	59.11	42115	77478
pyridine	-42	115	2.73	17	1.8	12	550	T1	IIA	79.10		
styrene	-31	145	3.6	30	1.1	8.0	490	T1	IIA	104.15		
tetrahydrofuran	-108	64	2.49	-17	2.0	11.8	224	T3	IIB	72.11	21617	40215
tetrahydrofurfuryl alcohol		178	3.52	70	1.5	9.7	280	T3	IIB			
toluene	-95	111	3.18	6	1.2	7	535	T1	IIA	92.14	3792	7885
triethylamine	-115	89	3.5	0	1.2	8			IIA	101.19		
trimethylamine	-117	3	2.04		2.0	11.6	(190)	(T4)	IIA	59.11		
1,3,5-trioxane	62	115	3.11	(45)	3.6	29	410	T2	IIB			
turpentine		149		35	0.8		254	T3	IIA			
Xylene	-25	144	3.66	30	1.0	6.7	464	T1	IIA	106.17		

APPENDIX 7

Cable Data

Cable Data

The general concept of intrinsic safety is that sparks caused by breaks and shorts in conductors of interconnecting cables will not cause ignition. Thus *from a hazardous area viewpoint* cables do not need to be mechanically protected to the degree required for non-intrinsically safe circuits.

The following points should, however, be considered when selecting cables for intrinsically safe circuits.

- The mechanical protection (SWA etc.) should be suitable for the general installation and such as to conform to any other requirements. This is especially true for circuits which are carrying signals which are of a critical nature for plant operational safety.

- Care should be taken to select cables which will not deteriorate due to corrosive action from chemicals and general plant environment.

- Do not run intrinsically safe and non-intrinsically safe cables in the same multicore cable.

- To avoid having to consider the effect of faults between different intrinsically safe circuits in a multicore, use a cable which conforms to Type A requirements. (See Chapter 12.)

- Core insulation should be such that the insulation will withstand a 500 V test between other cores, and between any core and the screen (if fitted) or metal sheath (if fitted), and between any screen and metal sheath, and between each screen if more than one screen is fitted.

- Possible stored energy in interconnecting cables should be considered and shown safe if the hazardous area is gas group

IIC or if the interconnecting cable is particularly long.[*]

- ☐ The minimum conductor sizes permitted for intrinsic safety will, in practice, be met without difficulty and except in very unusual applications (where the circuit has an especially high current) do not need consideration.

- ☐ If it is necessary to measure cable parameters on installed cable, the measurements should be made in the non-hazardous area, with the test instrument connected to the cable via suitable associated apparatus such as a low voltage dual channel zener barrier (2 V 5Ω or 4 V 10 Ω). The in-line resistance of the barrier must be measured separately and deducted from the measured value for cable resistance. Galvanic isolators cannot be used as the associated apparatus for these measurements.

If cable parameters require consideration, the following points will be of assistance.

Cable Capacitance Considerations

If the intrinsically safe circuit is operating above 20 V, the limiting parameter will normally be capacitance.

If typical capacitance values cannot be obtained from the cable supplier, measure the capacitance at 1 kHz or 10 kHz.

Cable Inductance Considerations

Inductance will normally be the limiting factor at lower voltage circuits.

Measurements should be made at 1 kHz or 10 kHz. Use of the

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* It is unlikely that cable lengths of less than 1 km will cause problems.

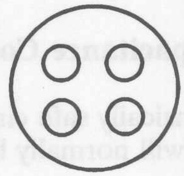
inductance to resistance ratio value (see Chapter 12) will usually make for easier measurements.

Cable lengths of as little as 10 m will normally be sufficient to give a reasonably accurate result. The worst case inductance will be encountered by measuring the two cores furthest apart. The form of the cable (whether coiled or run out) will not have any appreciable effect on the measurement.

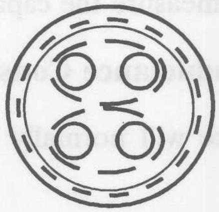
As a guide, the following cable data gives typical results.

Twin conductor plus screen
Conductor size 16 x 0.2 mm
Typical L/R = 17 μH/Ω
C = 13.4 nF/km
L = 0.67 mH/km

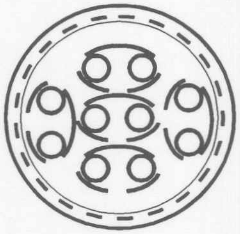
2- pair, 4-core conductor, no screen
Conductor size 24 x 0.2 mm
Typical C = 61.5 nF/km
L = 0.77 mH/km



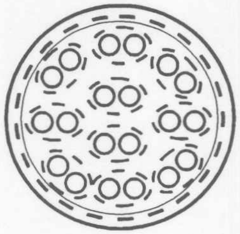
2-pair, 4-core conductor
each pair individually screened
overall SWA
Conductor size 16 x 0.2 mm
Typical L/R = 19 μH/Ω
C = 23.9 nF/km
L = 0.74 mH/km



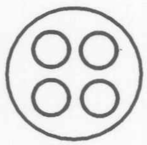
5-pair, 10-core conductor
each pair individually screened
overall SWA
Conductor size 16 x 0.2 mm
Typical L/R = 21 μH/Ω
C = 15.6 nF/km
L = 0.8 mH/km



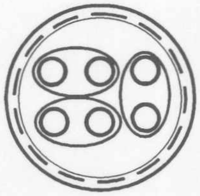
10-pair, 20-core conductor
each pair individually screened
overall SWA
Conductor size 16 x 0.2 mm
Typical L/R = 16 μH/Ω
C = 17.3 nF/km
L = 0.61 mH/km



2-pair, 4-core conductor
no screen or SWA
Conductor size 7 x 0.2 mm
Typical L/R = 4.4 μH/Ω
C = 300 pF/m
L = 0.75 μH/m



3-pair, 6-core conductor
overall screen, no SWA
Conductor size 16 x 0.2 mm
Typical L/R = 14 μH/Ω
C = 570 pF/m *
L = 0.7 μH/m **



* worst value is between screen, and all cores interconnected
** worst value is between two adjacent cores

INDEX

Although the index includes a good cross reference to the main topics, not every mention of an indexed subject is included. For example, numerous references are made to minimum ignition curves throughout the book, but only the main explanatory references are noted in the index.